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HISTORY OF THE WINTER SIMULATION CONFERENCE: OVERVIEW AND NOTABLE FACTS AND FIGURES

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ABSTRACT

The Winter Simulation Conference (WSC) is the leading international forum for disseminating recent advances in computer simulation. WSC also provides an unmatched occasion for interactions between simulation practitioners, researchers, and vendors working in all disciplines and in the academic, governmental, industrial, and military sectors. In this paper we discuss key aspects of WSC's evolution over the past fifty years. The discussion is based on our examination of all WSC *Proceedings* papers published between 1968 and 2016, which collectively document much of the history of simulation and WSC. We gather and summarize interesting facts and figures about WSC authors and their *Proceedings* papers so as to gain insights into conference dynamics and the interconnections between notable authors and between highly cited papers. We extract relevant information from the Web of Science, Scopus, and Google Scholar databases; and we present network visualizations of the interconnections between authors and between papers.

1 INTRODUCTION

The Winter Simulation Conference (WSC) is focused on the practice and theory of discrete-event and combined discrete-continuous simulation. Over the course of fifty years, WSC has evolved along with rapidly unfolding developments in technology, engineering, science, and societal needs. Specifically, WSC has broadened its scope by progressing in the following ways:

- from relatively simple applications involving the General Purpose Simulation System (GPSS) to large-scale applications involving grid and cloud computing, web-based simulation, and distributed simulation;
- from applications involving elementary statistical and mathematical methods to practical and theoretical advances in the statistical and applied mathematical sciences that are motivated by simulation-related problems; and
- from applications involving relatively low-resolution process-interaction models of operations in industrial, governmental, and military systems to applications involving, for example, high-resolution

discrete-continuous or agent-based models for addressing global issues in social and behavioral dynamics, environmental dynamics, homeland security, emergency response, and healthcare (Winter Simulation Conference 2017).

With this expanded scope, WSC brings together practitioners and researchers from around the world to stimulate high-impact innovations for solving urgent societal problems.

During the period 1967–2016, the WSC *Proceedings* was published in 47 volumes altogether containing about 10,000 papers written by about 12,600 authors. Note the following:

- There was no *Proceedings* for the 1967 conference, although 17 papers presented at the conference were published in a special issue of the *IEEE Transactions on Systems Science and Cybernetics* (Volume SSC-4, Number 4, November 1968) edited by Julian Reitman, the 1967 program chair.
- WSC was not held in 1972 and 1975 as explained in Sections 2.1 and 2.2 below.
- The WSC '17 *Proceedings* was not available when this paper was written.

The current collection of WSC *Proceedings* papers documents much of the history of the simulation field and the conference. Figure 1 is a graph of the dataset representing the number of WSC papers published each year during the period 1968–2016. This dataset was pulled from various sources, including the WSC website www.wintersim.org and the Association for Computing Machinery (ACM) website www.acm.org; and it was also checked manually. These published WSC papers have in turn been cited frequently in subsequent conference papers and archival journal articles not only in the simulation literature but also in the literature of many other fields.

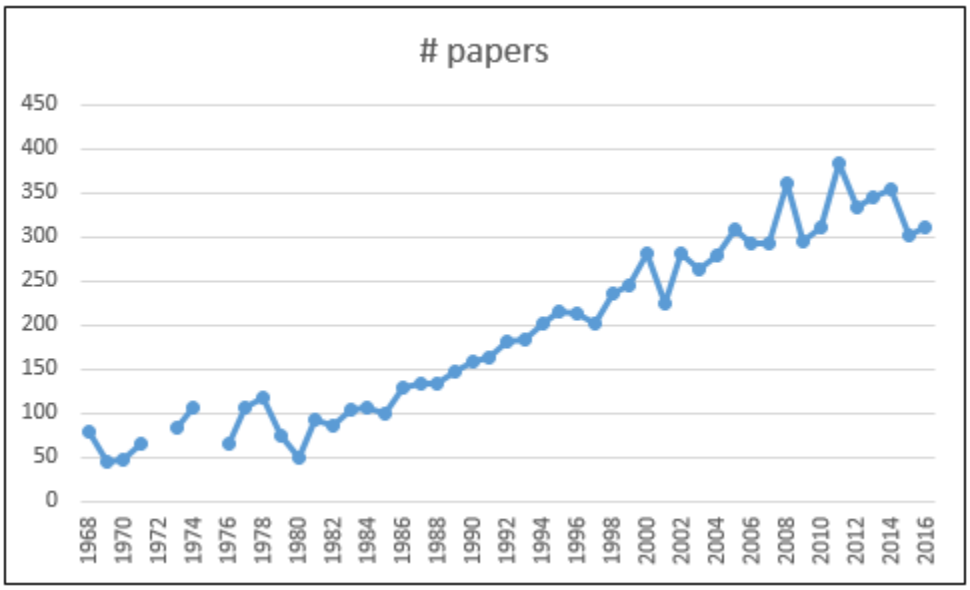

Figure 1: Number of WSC papers from 1968–2016.

Our objective is to present interesting facts and figures about WSC in order to understand and evaluate WSC's dynamics and the linkages between notable WSC authors and between highly cited WSC papers. This rest of this paper is organized as follows. In Section 2 we give a brief overview of the principal developments in each period of WSC's history. In Section 3 we outline the methodology used to extract relevant information about WSC from the Web of Science, Scopus, and Google Scholar databases. The extracted information is tabulated and discussed in Section 4. In Section 5 we use Gephi, a software

package for studying and visualizing networks, to analyze and depict the linkages between authors and between papers. Concluding remarks are given in Section 6.

2 CONFERENCE HISTORICAL OVERVIEW

To make this article self-contained, we present a synopsis of WSC's history based on division of that history into the following time periods:

- Origins and Early Years (1967–1974);
- Renaissance Period (1975–1982);
- Coming-of-Age Period (1983–1992);
- Period of Growth, Consolidation, and Innovation (1993–2007); and
- Modern Era (2008–2017).

We discuss each period briefly and provide references to the associated full paper covering that period in the rest of the WSC '17 Track on the History of Simulation. For papers on the general history and dramatic growth of the simulation field, see, for example, Goldsman et al. (2009, 2010) and Powers et al. (2012).

2.1 Origins and Early Years (1967–1974)

Schriber et al. (2017) chronicle developments during the WSC's early years (1967–1974). At that time simulation was widely regarded as the "method of last resort," especially in academia. Nevertheless during WSC's early years, simulation was increasingly recognized as an effective method for modeling and analyzing certain types of operations in industrial, governmental, and military systems. The following factors contributed to this trend: computers were becoming faster; user-friendly simulation software and support utilities were becoming more widely available; numerous technical societies and vendor-based user groups were becoming more interested in practical applications of simulation; and governmental and military organizations were steadily increasing their use of simulation.

Among simulation pioneers and WSC's founders, Arnold Ockene, Harold Hixson, and Julian Reitman were instrumental in organizing the 1967 conference, which focused primarily on applications using GPSS and new implementations of that simulation language. In 1968 the conference was expanded in scope to encompass all simulation languages as well as all other aspects of simulation, and a softbound *Proceedings* was published to provide a permanent record of each paper presented at the conference. By 1974 WSC had gained sponsorship from the following professional societies: AIIE, the American Institute of Industrial Engineers (now IISE, the Institute of Industrial and Systems Engineers); ACM; the Systems Science and Cybernetics Group of IEEE, the Institute for Electrical and Electronics Engineers (now IEEE/SMC, the Systems, Man, and Cybernetics Society of IEEE); SHARE, the user group for IBM mainframe computers; SCS, the Society for Computer Simulation (now the Society for Modeling and Simulation International); The College on Simulation and Gaming of The Institute of Management Sciences (now INFORMS-SIM, the Simulation Society of INFORMS, the Institute for Operations Research and the Management Sciences); and ORSA, the Operations Research Society of America (now INFORMS). Trends in WSC attendance included rapid growth peaking in 1971, followed by substantial decline. The number of papers appearing in the *Proceedings* exhibited a slow increase during WSC's early years. Although most of these papers were on simulation applications, several theory-oriented papers also appeared in the *Proceedings* each year after 1967.

2.2 Renaissance Period (1975–1982)

The 1974 WSC was a successful affair with good attendance and an increase in the number of papers compared with all previous years. But for reasons explained in Sargent et al. (2017) (including failure to

close the 1974 books and the subsequent disarray in conference leadership), it was not possible to hold a 1975 conference with the official participation of all WSC's sponsors at that time.

Fortuitously, thanks to the strenuous efforts of Harold Highland, Paul Roth, and Bob Sargent, WSC was reborn in 1976. In fact, this era was marked by a renaissance as the conference experienced a number of very positive developments. First, the Board of Directors was formally established, and written bylaws were put in place to prevent mismanagement in the future. In addition to retaining its previous sponsors, WSC gained sponsorship from the National Bureau of Standards (now NIST, the National Institute of Standards and Technology). Second and equally important, the program was expanded greatly to include coordinated sessions.

2.3 Coming-of-Age Period (1983–1992)

This era was marked by steady growth in conference participation, both in terms of attendance and the number of papers published. WSC was maturing and emerging as a major international conference on computer simulation. Sargent (2017) reports on this successful period in the conference's history. In particular, the program structure became more formalized, and it now included well-organized tracks, e.g., introductory tutorials, state-of-the-art tutorials, analysis methodology, modeling methodology, vendor products, and various applications-oriented tracks such as manufacturing simulation, construction engineering, and health systems. Moreover, all papers were refereed and had to satisfy a minimum page limit. The *Proceedings* itself was now hardbound, and coeditors were introduced to handle the growing volume of papers to be refereed, edited, and published each year.

The conference also added an exhibits area, a Ph.D. Colloquium, and enhanced simulation user group meetings. Further, the conference gained the sponsorship of ASA, the American Statistical Association. A highlight of this era was the celebration of WSC's Twenty-Fifth Anniversary in 1992, which included a special keynote address and a special panel session by WSC's founders that together provided a consolidated history of the conference up to that time.

2.4 Period of Growth, Consolidation, and Innovation (1993–2007)

Barton et al. (2017) report on the period characterized by long-term growth and conference enhancements in the face of several significant challenges. On the positive side, WSC experienced rapid proliferation of new tracks and minitracks to match the expanding interests of WSC attendees—for example, logistics, supply chain management, and transportation; semiconductor manufacturing; simulation education; scheduling; agent-based modeling; risk analysis; and telecommunications.

A number of clever innovations resulted in tremendous added value for conference attendees, for instance: a poster session; simulation case-study tracks; "Titans of Simulation" special addresses; a preconference "Simulation 101" short course; a cross-fertilization track bringing together experts from wide-ranging research areas; and a celebration of WSC's Fortieth Anniversary in 2007, including a special session on landmark WSC papers published over four decades.

Of critical importance to the continued advancement of the conference was the development and launch of the WSC website www.wintersim.org in 1995, which was largely due to the extraordinary efforts of Peter Welch, WSC's first webmaster. The website quickly became the main vehicle for rapid dissemination of conference information. By 2000, an online paper-management system was developed for submission, review, revision, and final delivery to the publisher of all papers in the *Proceedings*. The *Proceedings* had been published as a hardbound volume since 1984; but it became progressively larger and more expensive to print, necessitating a switch to a softbound, two-volume format in 1998. Since 2005 the *Proceedings* has been published exclusively in portable document format (PDF) that is made available on a USB key, a CD, or from the conference website.

Although WSC was moving ahead and steadily growing during the period 1993–2007, it was not immune from world events. After the tragic events of September 11, 2001, WSC '01 was nearly cancelled;

instead the conference suffered a drop in attendance and revenue that persisted for the next two years. The good news is that WSC persevered, consolidated, and ultimately got through its difficulties to emerge as a more-innovative, stronger conference. With the future well-being of WSC in mind, a number of dedicated individuals created the WSC Foundation, and they raised substantial funding to serve as part of a self-insurance policy for WSC against unforeseen adverse events. Ultimately the conference emerged from this period without having to draw on the WSC Foundation's funds. The future was again looking bright.

2.5 Modern Period (2008–2017)

Alexopoulos et al. (2017) discuss the present-day era, during which the conference has enjoyed tremendous growth in various dimensions. First, a number of new tracks and minitracks have found great favor among attendees, perhaps the most significant being the inclusion of the Modeling and Analysis of Semiconductor Manufacturing (MASM) "supertrack." In addition, the conference added successful tracks covering a variety of special-focus areas such as simulation optimization, environmental and sustainability, and applications in area of quality, statistics, and reliability (QSR).

In terms of WSC administration, major developments included a reorganization of the sponsors into two groups. The technical cosponsors of WSC are: ASA; ASIM, Arbeitsgemeinschaft Simulation; IEEE/SMC; and NIST. The full cosponsors of WSC are: ACM/SIGSIM, the ACM Special Interest Group on Simulation; IISE; INFORMS-SIM; and SCS. Both sets of cosponsors are represented on the WSC Board of Directors. Moreover, the conference now has a formal agreement among the full cosponsors for financial underwriting of WSC, thus mitigating certain long-term risks that the conference had to deal with in the past. In parallel with these activities, the Board of Directors undertook a major revision of the bylaws in order to be in compliance with the requirements of all the sponsors.

Perhaps the most-notable characteristic of the Modern Period has been the internationalization of WSC. Now practitioners and researchers around the world are actively participating in all WSC activities. For example, the German simulation society ASIM became a technical cosponsor of WSC in 2012. Moreover, WSC '12 was held in Berlin and thus was the first WSC held outside the United States. Owing to the success of that conference, WSC '18 will be held in Gothenburg, Sweden; and future WSCs will undoubtedly travel to all corners of the globe. See Goldsman et al. (2017) for additional insights regarding the conference's worldwide reach.

3 METHODOLOGY AND DATA SOURCES

Now we turn our attention to a discussion of interesting facts and figures related to the WSC. First some words on the methodology and data sources that we employ.

In recent years, a great deal of attention has been devoted to finding methodologies for evaluating research performance. Many studies have investigated the efficacy of various data sources and research impact metrics. This section of our article discusses the data sources and impact metrics we used to study the papers that have appeared in the WSC *Proceedings* over the time period 1968–2016.

WSC's citation information was gathered from the three major citations databases: Google Scholar (GS), Scopus, and the Web of Science (WoS). According to Harzing and Alakangas (2016), Thomson Reuters' Web of Science was, until 2004, the only data source available for citation analysis, and it has the reputation of being the "gold standard" for this purpose (Harzing and Alakangas 2016, Bauer and Bakkalbasi 2005). Elsevier's Scopus arose as an alternative to WoS in 2004, with greater coverage of open access and international journals; it seems to have lacked depth of coverage for certain earlier years and certain scientific journals (Bauer and Bakkalbasi 2005), though now it is widely used and accredited (Harzing and Alakangas 2016). Google Scholar was also introduced in 2004, although Google has not been particularly explicit about the material indexed — which is interpreted by many as its major drawback (Bauer and Bakkalbasi 2005). Harzing and Alakangas (2016) also discuss the questionable quality behind

the numbers displayed by GS, as its coverage includes "low-quality publications" such as blogs or magazine articles available on academic-related websites as well as "stray citations," where minor variations can lead to duplicate records for a single paper. However, as the authors also emphasize, these drawbacks should not discourage the use of GS, since the other databases also occasionally encounter similar problems. In addition, two later studies (Harzing 2013, 2014) showed that the GS database is suitable for comparisons, as it displays stability over time and has a fairly large coverage.

It was often the case that constructions of WSC databases resulted in several years of missing data or at least inconsistent data from search to search (an especially common characteristic of the GS searches). Thus, beginning in December 2016, we conducted repeated reconstructions of our WSC databases from GS, Scopus, and WoS to ensure stability and completeness of the results. GS citation data was collected via the software Publish or Perish (2017). The software was also used to import Scopus and WoS databases, to have all datasets in the same format, facilitating further comparisons. Typical results of the various searches are displayed in Table 1, which gives the total number of cited entities broken up by time intervals (publication years) and index. As explained below, the term "entities" can denote full papers, abstracts, nonrefereed case studies, and just about anything else.

Table 1: Number of cited WSC entities. Data compiled from the GS, Scopus, and WoS databases.

Source \ Pub. Years	1968–1978	1979–1989	1990–2000	2001–2011	2012–2016	Total
GS (3/20/17)	872	1,201	2,502	4,096	1,955	10,626
Scopus (3/1/17)		1,034	2,134	3,384	1,596	8,148
WoS (2/21/17)			1,732	3,388	1,039	6,159

GS produces the largest numbers (since it is more liberal regarding its definition of a "paper"), followed by Scopus, and then WoS bringing up the rear. In addition, we note that the Scopus data in Table 1 is missing an entire year (2014) during the period 2012–2016, while the WoS numbers run only until 2014. In fact, at the times of our searches, among the three sources, only GS had data ranging over the entire span 1968–2016. That being said, Figure 2 depicts the total number of cited entities from GS on a yearly basis, superimposed on what amounts to the number of papers depicted in Figure 1. By "entities," we refer to anything that can be cited by GS, including regular papers, but also including such interlopers as one-page Keynote and Titan addresses (sometimes only containing an abstract and author biography), informal vendor talks (often not adhering to WSC standard formatting rules), Ph.D. Colloquium talks (sometimes full papers, sometimes merely abstracts), and nonrefereed case studies. Moreover, papers may be double-cited due to small typographical errors in the citations themselves. For these reasons, we find that the number of cited entities is frequently greater than the number of standard WSC papers. On the other hand, we occasionally observe that the number of cited entities is less than the number of papers. This latter phenomenon could arise due to the possibility that a particular paper might not have garnered any citations at all, GS / Scopus / WoS database errors, etc. All told, our tally of the total number of WSC papers from the period 1968–2016 comes out to 9,208, while the GS list of cited entities reports in at 10,626 entries. Henceforth, and in spite of the differences, we will often use the terms "entities" and "papers" synonymously, especially when the context is obvious.

Table 2 gives the number of citations broken up by time interval and citation index. We again see that GS reports more citations than do Scopus and WoS, and over a longer time horizon. Of course, many of those GS citations result from nonrefereed entities; but nevertheless, GS can be used for apples-to-apples comparisons over a wider range of years.

Figure 3, which complements Table 2, depicts the number of Google Scholar citations garnered by WSC papers categorized by year of publication. For example, the figure shows that WSC papers published in 1986 have so far received a total of more than 6,300 citations. In fact, the total number of citations from all years currently (as of 10/10/17) stands at 139,030. We see that early WSC papers have received only a modest number of citations, but as the years have gone by, the citation counts have increased tremendously.

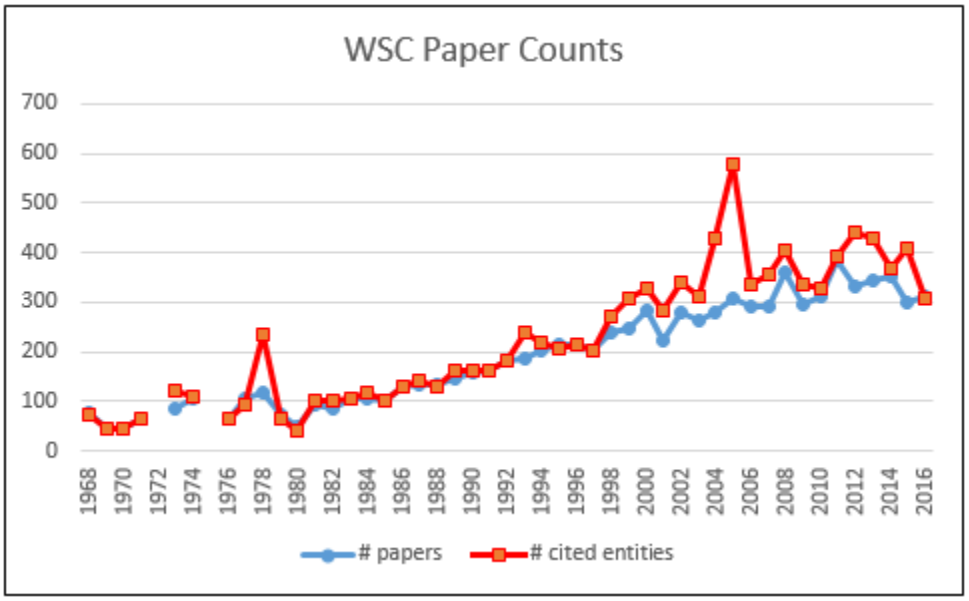

Figure 2: Numbers of WSC papers and GS-cited entities from 1968–2016.

Table 2: Number of citations of WSC entities papers by year of publication, 1968–2016. Data compiled from the GS, Scopus, and WoS databases.

Source \ Pub. Years	1968–1978	1979–1989	1990–2000	2001–2011	2012–2016	Total
GS (10/10/17)	2,277	16,376	50,791	62,566	7,020	139,030
Scopus (3/1/17)		2,604	14,505	22,992	1,178	41,279
WoS (3/1/17)			3,750	10,473	438	14,661

Lower citation counts in recent years reflect the fact that the papers from those years have simply not been around long enough to obtain the citation counts that they will eventually earn.

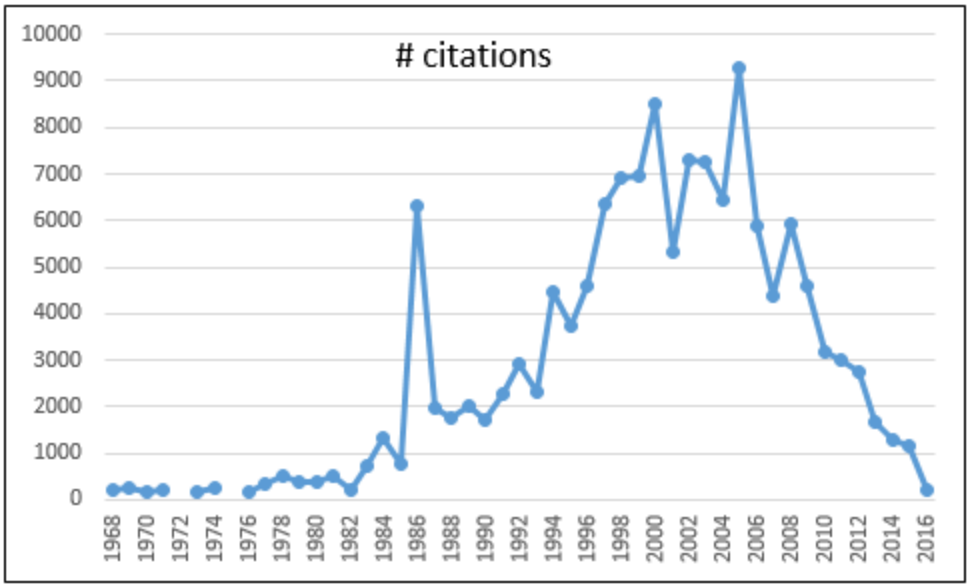

Figure 3: Number of Google Scholar citations of WSC entities by year of publication, 1968–2016 (data compiled 10/10/17).

4 SOME FACTS AND FIGURES

The remaining analyses will be conducted on the basis of queries made during the period March–October, 2017 from all the three sources — GS, Scopus, and WoS — focusing on citations. Section 4.1 looks into articles having the most citations; Section 4.2 discusses popular subject areas over the years; Section 4.3 makes some remarks on notable numerical accomplishments on the level of individual authors; Section 4.4 concerns longtime, "old-timer" WSC participants; and Section 4.5 provides a listing of some interesting WSC paper titles that have appeared over the years.

4.1 Highly Cited papers

It is first natural to ask about the most-cited papers among the approximately 10,000 articles. The distinction of the highest total goes to Devroye (1986) for his tutorial on nonuniform random variate generation, with over 4,000 GS citations; see Figure 4. The second-most-cited WSC paper according to GS is Sargent's (2005) verification and validation tutorial, which has accumulated almost 2,000 citations, although its various other incarnations from other years add significantly to that total; this paper also has 108 WoS citations and 261 on Scopus, reflecting the smaller values typically associated with those indexes.

Table 3 lists the top fifty papers in terms of GS citations. These articles cover a wide range of subject areas, with many tending to be tutorials, particularly in the areas of verification and validation (V&V) and optimization. Even the article clocking in at the 50th slot is well-positioned to soon hit 200 citations.

4.2 Popular Subject Areas

One would expect that interests in simulation might evolve over time as certain subjects become trendy and others fall by the wayside. In fact, such trends seem to manifest with regard to the areas of interest to WSC authors. We took the WSC title database covering the period 1968–2016 and tabulated the title words

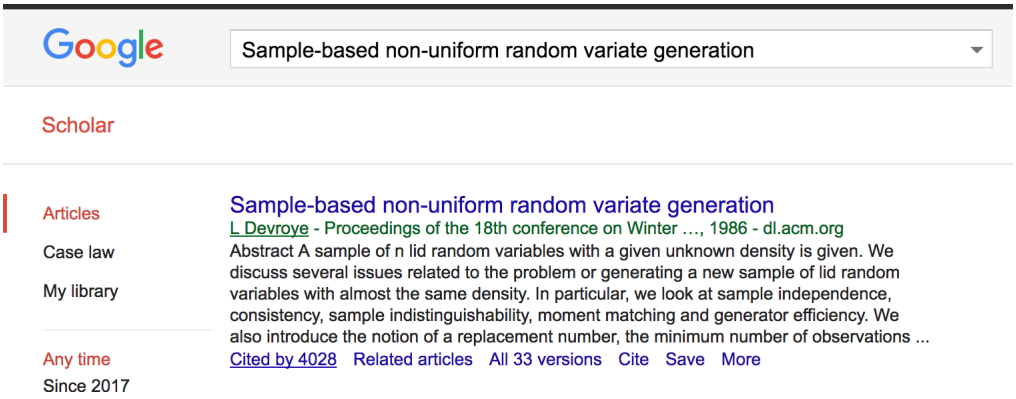

Figure 4: Google Scholar's most-cited WSC paper, Devroye (1986).

that appeared most frequently each year. Table 4 abstracts a small portion of that database, highlighting the 25 or so most-frequently appearing title words for the years 1968, 1992, and 2015. Certain words have so many variations (e.g., "model", "models", "modeling", etc.) that we have categorized our lists by word group, where a "group" is simply a set of "practically equivalent" words. In any case, any word that appears in the lists is simply a surrogate for the entire word group. Moreover, we have cleaned from the database any trivial or useless words such as "a", "the", "using", etc.

We see that certain obvious words — e.g., "simulation," "model," and "system" — have remained at the top of the heap for all fifty years. But once-popular subject areas such as GPSS are no longer to be found, while "optimization" is rapidly rising up the charts as it enjoys tremendous interest as of late.

4.3 Author Honor Role

We now turn to various results related to author productivity; namely, we list the following in Table 5: (i) the 25 "most-prolific" WSC authors (i.e., those having the largest number of publications in the WSC *Proceedings* over the years); and (ii) the 25 most-highly cited authors. We conducted the former analysis using our own database plus a little elbow grease, and the latter analysis using our Google Scholar database, since this index gives dramatically large numbers that look really good.

It is simply amazing how many papers have been written by certain individuals, and how many citations have been garnered by others. Authors Nelson and Wilson, for instance, are both poised to go over the WSC publication century mark in the coming years. Note that Nelson and Wilson could have been even a little closer to that bar, but we decided not to award them an extra publication, even though the author Barry Wilson presented in 1988 — we simply have no proof that Nelson and Wilson are (or ever have been) one and the same. Meanwhile, authors Sargent and Devroye are running neck-and-neck with respect to citation count. It seems that Devroye was more of the hare with one enormously cited publication from 1986, while Sargent has been more of the patient tortoise with several publications that have accrued citations somewhat more evenly over time.

4.4 Old-Timers Club

One of the unique characteristics of the WSC is the tremendous devotion of its attendees. Of course, as the years have marched on, certain young whippersnappers have matured into seasoned WSC veterans. Some of these long-time attendees have earned (or are poised to earn) honorary membership in the Old-Timers 30-Year Club, where the only qualification for membership is having published a paper in the *Proceedings* for at least 30 WSCs. Note that this qualification is not equivalent to having *attended* at least 30 WSCs, an achievement that we cannot verify using our databases. Table 6 lists the Club's current members, though we may have missed a couple of deserving participants if they gave presentations that we have not been

Table 3: Fifty most-cited WSC papers according to Google Scholar (3/20/17).

Cites	Author(s)	Year	Title
4028	L Devroye	1986	Sample-Based Non-Uniform Random Variate Generation
1867	RG Sargent	2005	Verification and Validation of Simulation Models
879	CM Macal, MJ North	2005	Tutorial on Agent-Based Modeling and Simulation
591	RG Sargent	2004	Validation and Verification of Simulation Models
500	V Paxson, S Floyd	1997	Why We Don't Know How to Simulate the Internet
465	AM Law	2008	How to Build Valid and Credible Simulation Models
421	X Chang	1999	Network Simulations with OPNET
397	RE Shannon	1998	Introduction to the Art and Science of Simulation
380	MC Fu, FW Glover, J April	2005	Simulation Optimization: A Review, New Developments, ...
365	Y Carson, A Maria	1997	Simulation Optimization: Methods and Applications
352	BJ Angerhofer, MC Angelides	2000	System Dynamics Modelling in Supply Chain Management: ...
349	A Maria	1997	Introduction to Modeling and Simulation
346	H Schwetman	1986	CSIM: A C-Based Process-Oriented Simulation Language
338	CD Pegden	1984	Introduction to SIMAN
331	J April, F Glover, JP Kelly, M Laguna	2003	Simulation-Based Optimization: Practical Introduction to ...
300	F Azadivar	1999	Simulation Optimization Methodologies
287	GT Nguyen, RH Katz, B Noble	1996	A Trace-Based Approach for Modeling Wireless Channel ...
285	PP Bonissone	1980	A Fuzzy Sets Based Linguistic Approach: Theory and ...
283	JR Swisher, PD Hyden, SH Jacobson	2000	A Survey of Simulation Optimization Techniques and ...
280	JS Carson II	2004	Introduction to Modeling and Simulation
280	R Fujimoto	2015	Parallel and Distributed Simulation
273	O Balci	1997	Verification, Validation and Accreditation of Simulation ...
269	JS Dahmann, RM Fujimoto, RM Weatherly	1997	The Department of Defense High Level Architecture
254	MS Meketon, B Schmeiser	1984	Overlapping Batch Means: Something for Nothing?
251	YM Lee, F Cheng, YT Leung	2004	Exploring the Impact of RFID on Supply Chain ...
249	S Andradóttir	1998	A Review of Simulation Optimization Techniques
243	PA Fishwick	1996	Web-Based Simulation: Some Personal Observations
240	PW Glynn	1987	Likelihood Ratio Gradient Estimation: An Overview
239	CM Macal, MJ North	2009	Agent-Based Modeling and Simulation
236	CS Chong, AI Sivakumar, MYH Low, KL Gay	2006	A Bee Colony Optimization Algorithm to Job Shop ...
234	S Das, R Fujimoto, K Panesar, D Allison	1994	GTW: A Time Warp System for Shared Memory ...
233	RR Barton	1998	Simulation Metamodels
216	W Müller, H Schumann	2003	Visualization for Modeling and Simulation: Visualization ...
205	RM Fujimoto	2001	Parallel Simulation: Parallel and Distributed Simulation ...
205	RG Ingalls	2008	Introduction to Simulation
204	RR Barton	1992	Metamodels for Simulation Input-Output Relations
199	S Ólafsson, J Kim	2002	Simulation Optimization
198	J Banks	1999	Introduction to Simulation
197	RG Sargent	2000	Verification, Validation, and Accreditation: Verification, ...
196	O Balci	1998	Verification, Validation, and Accreditation
196	TJ Schriber, DT Brunner, JS Smith	2012	How Discrete-Event Simulation Software Works and Why ...
192	SM Sanchez, TW Lucas	2002	Exploring the World of Agent-Based Simulations: Simple ...
190	S Robinson	1997	Simulation Model Verification and Validation: Increasing ...
184	JPC Kleijnen	1999	Validation of Models: Statistical Techniques and Data ...
182	DD Dudenhoeffer, MR Permann, M Manic	2006	CIMS: A Framework for Infrastructure Interdependency ...
181	CD Pegden	1983	Introduction to SIMAN
180	O Balci	1990	Guidelines for Successful Simulation Studies ...
179	D Hajjar, S AbouRizk	1999	Simphony: An Environment for Building Special Purpose ...
179	S Samaha, WS Armel, DW Starks	2003	Emergency Departments I: The Use of Simulation ...

Table 4: Number of word appearances in WSC titles.

1968		1992		2015	
Word Group	#	Word Group	#	Word Group	#
simulation	54	simulation	111	simulation	233
system	20	model	46	model	143
model	15	system	31	system	56
computer	12	process	16	optimization	54
GPSS	8	manufacturing	15	agent	40
network	6	analysis	13	analysis	35
program	6	generator	12	multi	35
design	6	optimization	12	approach	32
analysis	5	design	11	discrete	25
process	5	network	10	event	22
product	5	methodology	10	performance	22
application	5	evaluation	9	evaluation	21
development	4	discrete	9	framework	21
job	4	object	9	stochastic	21
experiments	4	application	8	data	19
generator	4	variate	8	process	19
Monte Carlo	4	parallel	8	interval	19
shop	3	environment	7	dynamic	18
response	3	control	7	study	17
discrete	3	random	6	computer	16
distribution	3	animation	6	design	16
manufacturing	3	support	6	trans...	16
estimation	3	transaction	6	constraint	15
scheduling	3	experiment	6	uncertainty	15
state	3	approach	6	behavior	15
				methodology	15
				improve	15
				supply	15

Table 5: WSC 25 most-prolific authors and 25 most-cited authors, 1968–2016. The latter search was conducted via GS on 10/10/17.

Most Publications		Most Citations	
Author	# Publications	Author	# Citations
Barry L. Nelson	94	Robert G. Sargent	4,324
James R. Wilson	89	Luc Devroye	4,278
David Goldsman	77	Osman Balci	2,770
Averill M. Law	76	Richard Fujimoto	2,061
Thomas J. Schriber	75	Charles M. Macal	1,929
Robert G. Sargent	69	Pierre L'Ecuyer	1,737
Lee W. Schruben	68	Averill M. Law	1,681
Pierre L'Ecuyer	63	Michael J. North	1,665
Oliver Rose	61	Barry L. Nelson	1,555
Bruce W. Schmeiser	60	Fred Glover	1,525
Peter W. Glynn	55	Michael C. Fu	1,272
James O. Henriksen	51	Peter W. Glynn	1,271
Simaan M. AbouRizk	48	Russell R. Barton	1,244
Simon J. E. Taylor	47	David Goldsman	1,244
Richard E. Nance	47	Lee W. Schruben	1,231
Adelinde M. Uhrmacher	47	Susan M. Sanchez	1,194
Soemon Takakuwa	46	C. Dennis Pegden	1,180
Paul A. Fishwick	45	Paul A. Fishwick	1,165
Michael C. Fu	45	James P. Kelly	1,145
W. David Kelton	44	Stewart M. Robinson	1,133
Shane G. Henderson	43	James R. Wilson	1,086
Stephen D. Roberts	42	David M. Nicol	1,081
Osman Balci	41	Jay April	1,039
David M. Nicol	41	Bruce W. Schmeiser	997
John W. Fowler	40	Jerry Banks	986

counting as "full papers" — in which case we apologize and will immediately award membership when those cases are brought to our attention.

Table 6: Old-Timers 30-Year Club.

Member	# Years
Thomas J. Schriber	47
Averill M. Law	42
Robert G. Sargent	39
James R. Wilson	35
David Goldsman	33
Barry L. Nelson	32
Bruce W. Schmeiser	32
Lee W. Schruben	32
Peter W. Glynn	30
Pierre L'Ecuyer	30
Stephen D. Roberts	30
W. David Kelton*	29
Richard E. Nance*	29

*Initiate in 2017.

We make the following observations about Table 6. Club founder and scribe Schriber has been awarded one extra year of credit for a presentation that did not have an accompanying paper. Therefore as explained in Section 1, Schriber has accumulated the maximum possible number of years up to the present time, a record that is unlikely ever to be surpassed. Club lawyer Law and sergeant-at-arms Sargent have each been awarded an extra year due to misspellings that we caught in the official WSC title pages. Author Goldsman has been given no additional credit even though multiple family members (Gamze, Lynne, and Paul) have presented papers.

4.5 Interesting Paper Titles

WSC authors are a clever lot and occasionally come up with interesting paper titles that serve to stimulate interest in the associated talk. We have listed a small sampling of such titles in Table 7 and fully acknowledge that there are many, many other deserving papers that are not on this particular list.

Some quick remarks. Fishman (1968) is included in the list merely because this is the first true research paper that appears in any WSC *Proceedings*. Robert[4] et al. (1977) appears merely because this paper has four authors having the first name of "Robert," which we found to be amusing. Markowitz (1981) is included because, after all, Harry Markowitz — a long-standing member of the simulation community — won the 1990 Nobel Prize in Economics.

5 Network Analysis and Visualization

The various WSC *Proceedings* have accumulated a substantial collection of articles over the years, which facilitates an investigation of how authors and their publications are connected. Network analysis is a valuable class of tools that enable efficient visualization and understanding of how things (e.g., authors or papers) are related to each other. We undertook an elementary analysis our various datasets using the popular social network analysis software Gephi (gephi.org). In particular, Section 5.1 discusses a Gephi network analysis of what we term "prolific" authors; and similarly, Sections 5.2 and 5.3 are concerned with highly cited authors and papers, respectively. We conduct an author-connectivity analysis in Section 5.4, where we assign performance metrics akin to what is known as an "Erdős number" to every author

Table 7: Interesting paper titles.

Cool Authors	Cool Title
Fishman (1968)	Estimating Reliability in Simulation Experiments
Herman and Liu (1973)	The Daughter of Celia, the French Flag, and the Firing Squad
Blanning et al. (1974)	Training Socialist Managers by Enterprise Simulation
Robert[4] et al. (1977)	Energy Input-Output Simulation of Midwest Crop Production
Markowitz (1981)	Barriers to the Practical Use of Simulation Analysis
George (1982)	Super Mann-Whitney Simulation of System Reliability
Barnett (1983)	The 'Tell-Us-the-Answer-You-Want' Problem
Highland (1983)	A Dinosaur's View of Simulation (unpublished keynote address)
McLeod (1985)	But, Mr. President – Is It ETHICAL?
Meketon and Schmeiser (1986)	Overlapping Batch Means: Something for Nothing?
White (1987)	Simulation: Pushing a Dead Mouse Through a Maze?
Feuchter et al. (1991)	When Is a Satellite Not a Toaster?
Okashah and Goldwater (1994)	Unknown Unknowns: Modeling Unanticipated Events
Wilson (1997)	Conduct, Misconduct, and Cargo Cult Science
Reynolds (2002)	Linda Arouses a Sleeping Barber
Shapiro (2003)	Only Wet Babies Like Change
Cheng (2011)	Using Pearson Type IV and Other Cinderella Distributions in Simulation
Alexopoulos et al. (2011)	Overlapping Batch Means: Something More for Nothing?

[4]Citation should actually be Muller, Jr. et al. (1977) without an exponent.

pair. Section 5.5 complements the Erdős analysis by examining particularly "collegial" coauthor pairs — who are designated WSC BFFs (best friends forever).

5.1 Gephi Analysis of Prolific Authors

As a first example, we consider 25 prolific authors (not quite the same as those from Section 4.3) who have published a total of 865 WSC papers that have been cited in the WoS index during the period 2000–2014. Figure 5 depicts the Gephi network of these authors as they relate to others who have published in the WSC *Proceedings*. In the figure, each node represents a WSC author (although only these 25 are explicitly named). The size of a node is proportional to the number of papers written by that author, and edges connecting nodes signify collaboration between the corresponding nodes. For ease of illustration, we only present connected pairs for coauthors having at least two WSC papers together; this resulted in a graph with 206 nodes and 439 edges, which we found to be visually appealing.

Gephi offers a statistical analysis tool allowing for the computation of some commonly used bibliometrics such as page rank, average path length, and modularity (a measure of network "nearness"). In particular, modularity was used to create colorized clusters to visually detect related authors. Gephi implements the Louvain Method (Blondel et al. 2008) to generate the clusters.

The relatively large number of edges in a particular cluster (nodes having the same color) indicates a large degree of collaboration among colleagues common to that cluster. It is interesting to notice that there is collaboration among nodes in nearby clusters as well. There are also several isolated "island" clusters, but generally speaking, there is a great deal of connectivity in the graph.

Figure 6 incorporates the same authors as Figure 5; the only difference is that the node sizes in Figure 6 are proportional to the number of *citations* for each author, whereas in Figure 5 they are proportional to the number of *papers*. We see, for instance, that Sargent's node is larger in Figure 6 because of his relatively large number of WoS citations.

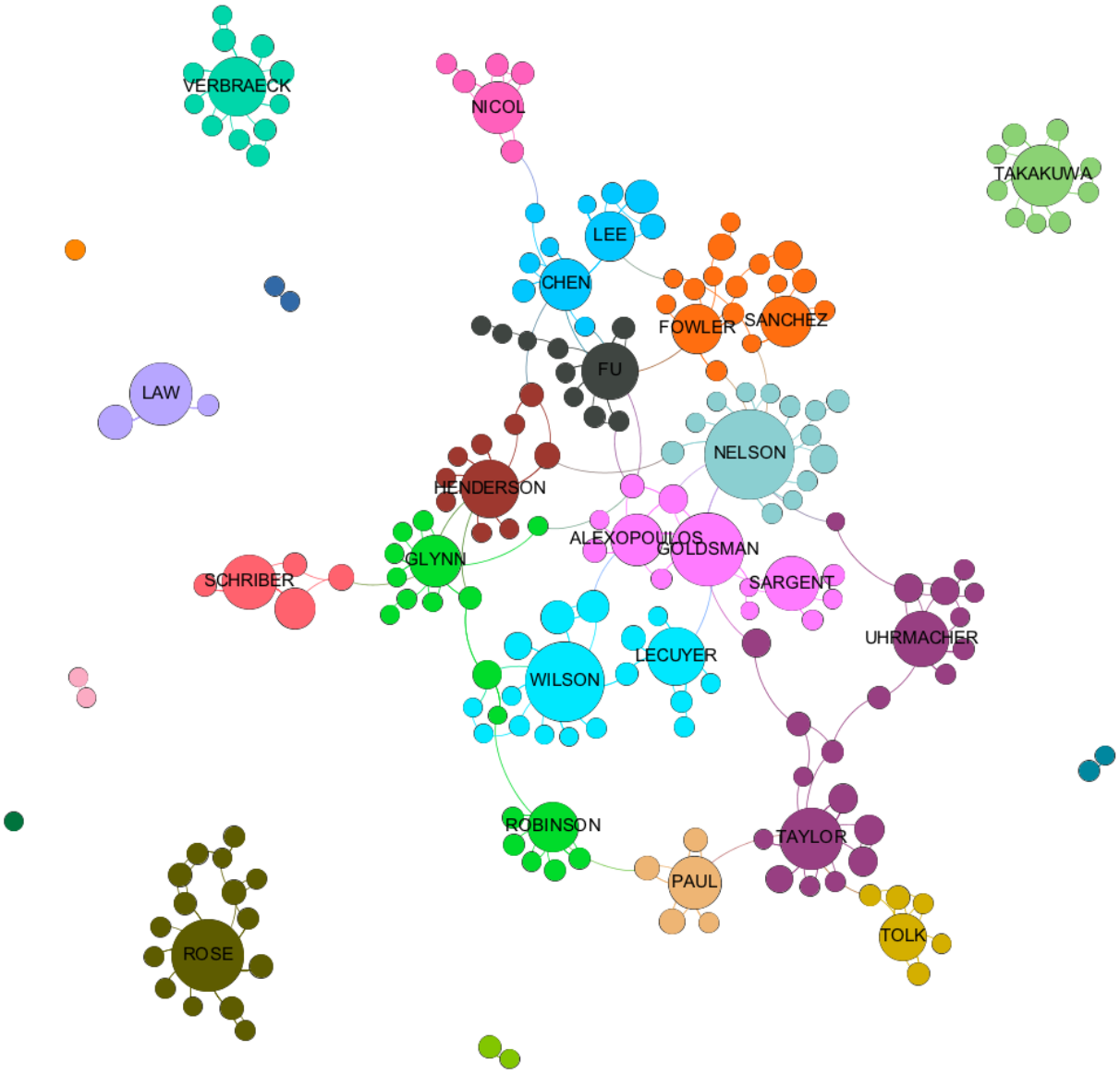

Figure 5: Gephi analysis — WSC network connections of 25 prolific authors for the period 2000–2014 (node size proportional to number of papers).

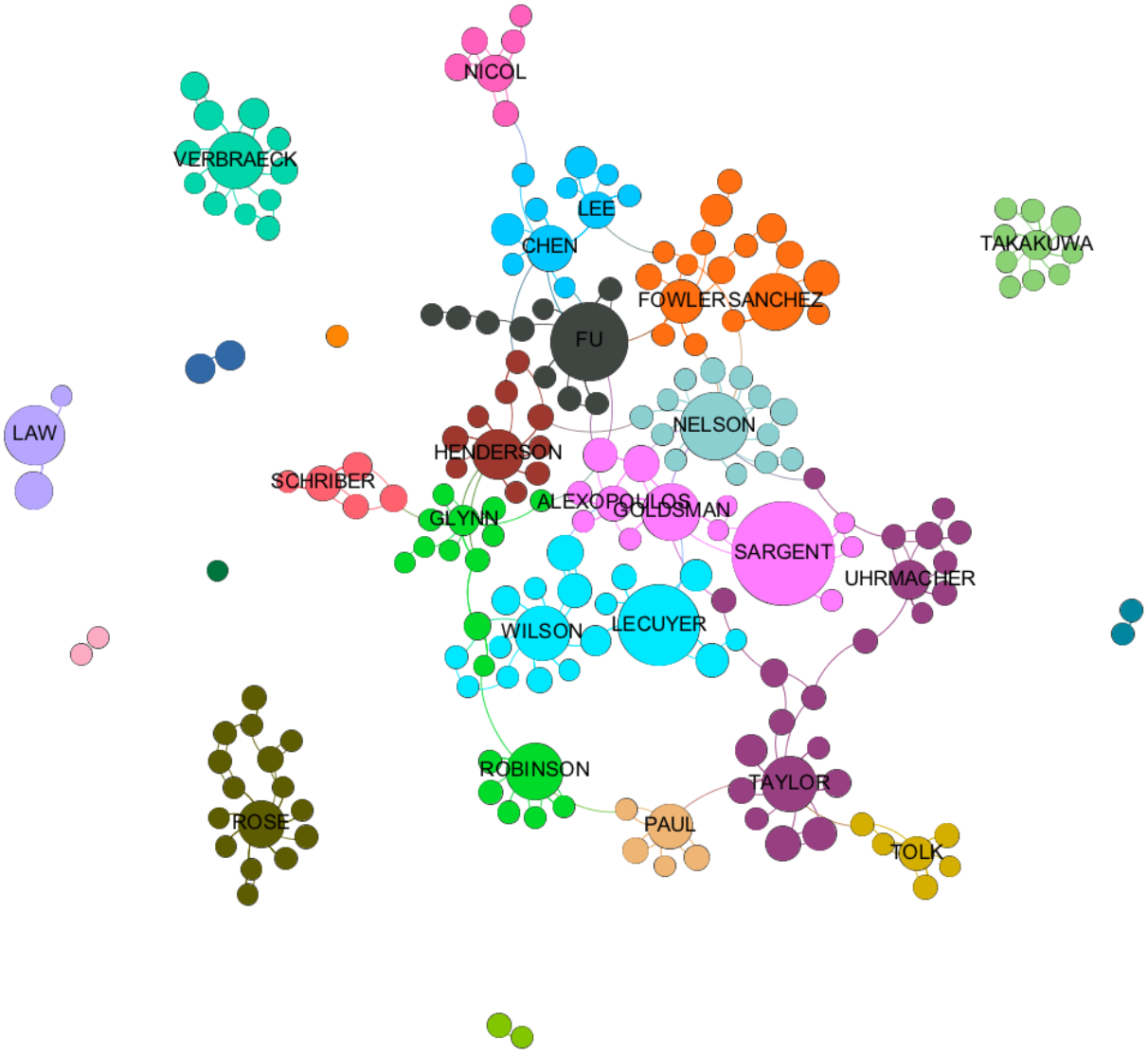

Figure 6: Gephi analysis — WSC network connections of 25 prolific authors for the period 2000–2014 (node size proportional to number of citations).

5.2 Gephi Analysis of Highly Cited Authors

We repeat the analysis of Section 5.1, but now for 25 highly cited authors according to WoS during the period 2000–2014 (not quite the same authors as those listed in Table 5). These authors collectively published 583 WSC articles (compared to 865 papers from the 25 prolific authors discussed in Section 5.1). The resulting Gephi network is depicted in Figure 7, where we again only include coauthor nodes with at least two papers.

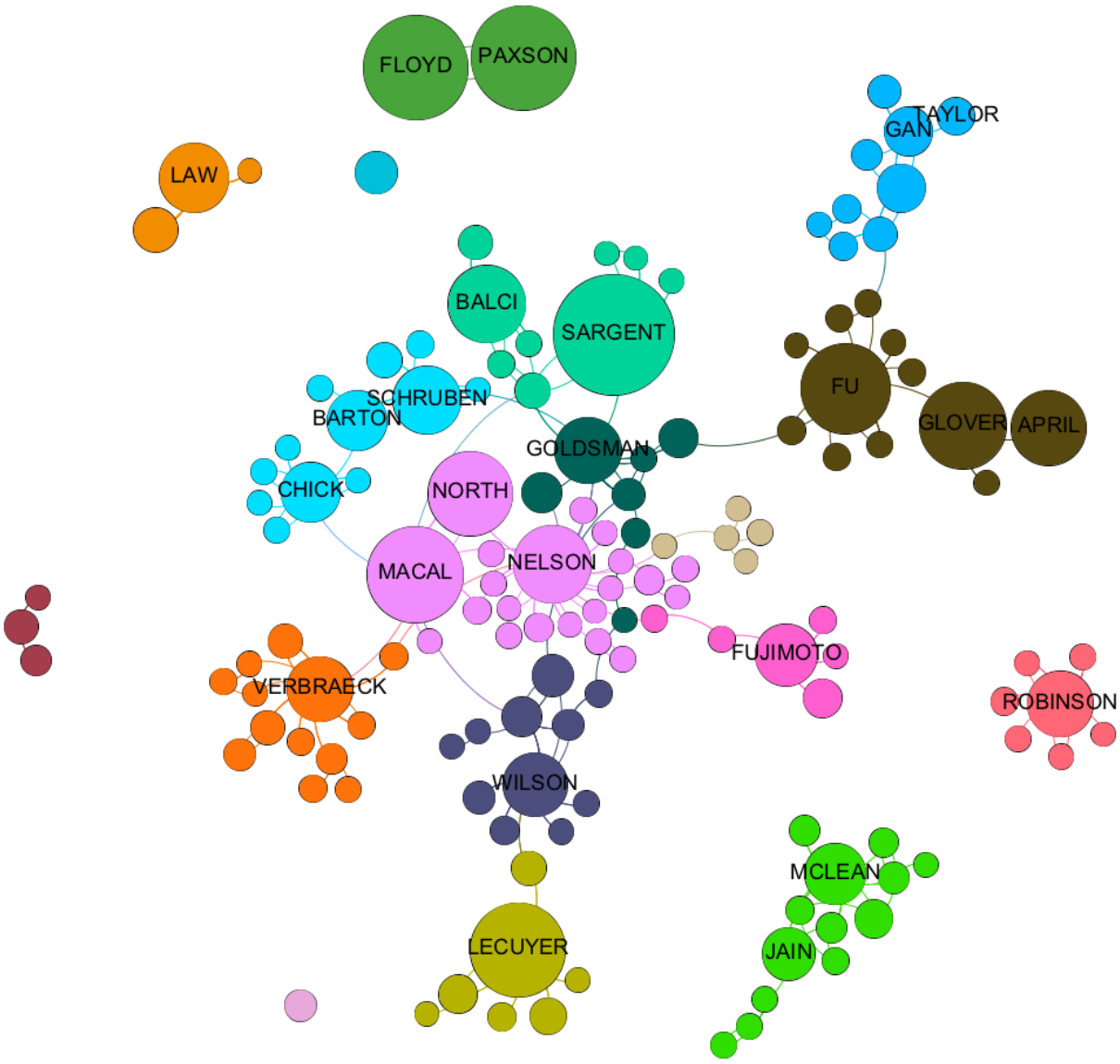

Figure 7: Gephi analysis — WSC network connections of 25 highly cited authors for the period 2000–2014 (node size proportional to number of citations).

We observe a smaller number of clusters in Figure 7 than for the prolific author graphs from the previous subsection. Moreover, some authors have switched clusters between the two analyses. Note that Floyd and Paxson — who have very impressive large nodes — are, in fact, coauthors.

5.3 Gephi Analysis of Highly Cited Papers

We repeat our graphing exercise with respect to 25 highly cited WSC papers according to the WoS database over the period 1990–2014. Figure 8 shows how these highly cited papers are connected to each other — a connecting edge indicates that one of the papers cites the other. Again, we only display (smaller) nodes having at least two edges.

From this graph, four well-defined clusters stand out: the green (formed by various Macal and North and related papers on agent-based modeling and simulation); the blue (consisting of a number of Sargent and related articles on verification, validation, and accreditation of simulation models); the purple (dealing with simulation optimization); and the black (concerning another stream of simulation optimization papers). The most-cited paper from this particular WoS database, Floyd and Paxson (2001), is on the topic "Difficulties in Simulating the Internet", and does not have edges to any of the other papers.

5.4 "Erdős Number" Analysis

The purpose of this section is to discuss the performance metric known as an "Erdős number" as it relates to connectivity among WSC authors (see https://en.wikipedia.org/wiki/Erd%C5%91s_number and https://oakland.edu/enp). To be assigned an Erdős number of 1, an author A must have written a paper with the prolific mathematician Paul Erdős. If an author B does not have an Erdős number of 1, but has written a paper with an author A who does, then B has an Erdős number of 2. More generally, an author's Erdős number is $k+1$, where k is the lowest Erdős number of any coauthor.

This concept easily applies if we limit our world to WSC papers. Now suppose that WSC-Erdős is the place holder for a generic WSC author. Similar to before, if WSC-Erdős and A are WSC coauthors, then A has a WSC-Erdős number of 1; and in general, A has a WSC-Erdős number of $k+1$, where k is now the lowest WSC-Erdős number of any of A's WSC coauthors. Thus, A's WSC-Erdős number indicates how far away A and WSC-Erdős are on the WSC paper authorship chain.

Table 8 provides some examples illustrating how many WSC authors have certain WSC-Erdős numbers for various choices of WSC-Erdős, where the numbers have been compiled for WSC papers appearing during the period 1968–2015. For instance, we see from the table that 40 WSC authors have a Wainer number of 1, i.e., Gabriel has had 40 distinct coauthors; and 1,759 WSC authors have a Wainer number of 4, indicating the incredible number of WSC authors that are only four stops away from Gabriel on the WSC authorship chain.

Table 8: How many WSC authors have WSC-Erdős numbers $k = 1, 2, \ldots, 11$ (1968–2015)?

WSC-Erdős \ k	1	2	3	4	5	6	7	8	9	10	11
Peter Glynn	31	292	1,195	1,797	1,095	461	191	62	47	19	3
Barry Nelson	105	994	1,995	1,144	631	193	75	44	9	3	
Robert Sargent	53	507	1,757	1,608	732	349	122	35	19	11	
Lee Schruben	72	854	1,814	1,313	659	319	87	37	29	6	3
Gabriel Wainer	40	305	1,261	1,759	1,097	450	184	61	23	13	
James Wilson	127	813	1,809	1,340	645	313	63	39	35	6	3

One immediately notices from Table 8 the near-exponentiation of connections as the various WSC-Erdős numbers increase up to about $k = 4$, after which the connections tail off — simply because our world of WSC authors is capped off at about 12,600. The short story is that there is tremendous connectivity among WSC authors. In addition, a number of extremely long chains — a few even stretch to length 11! For

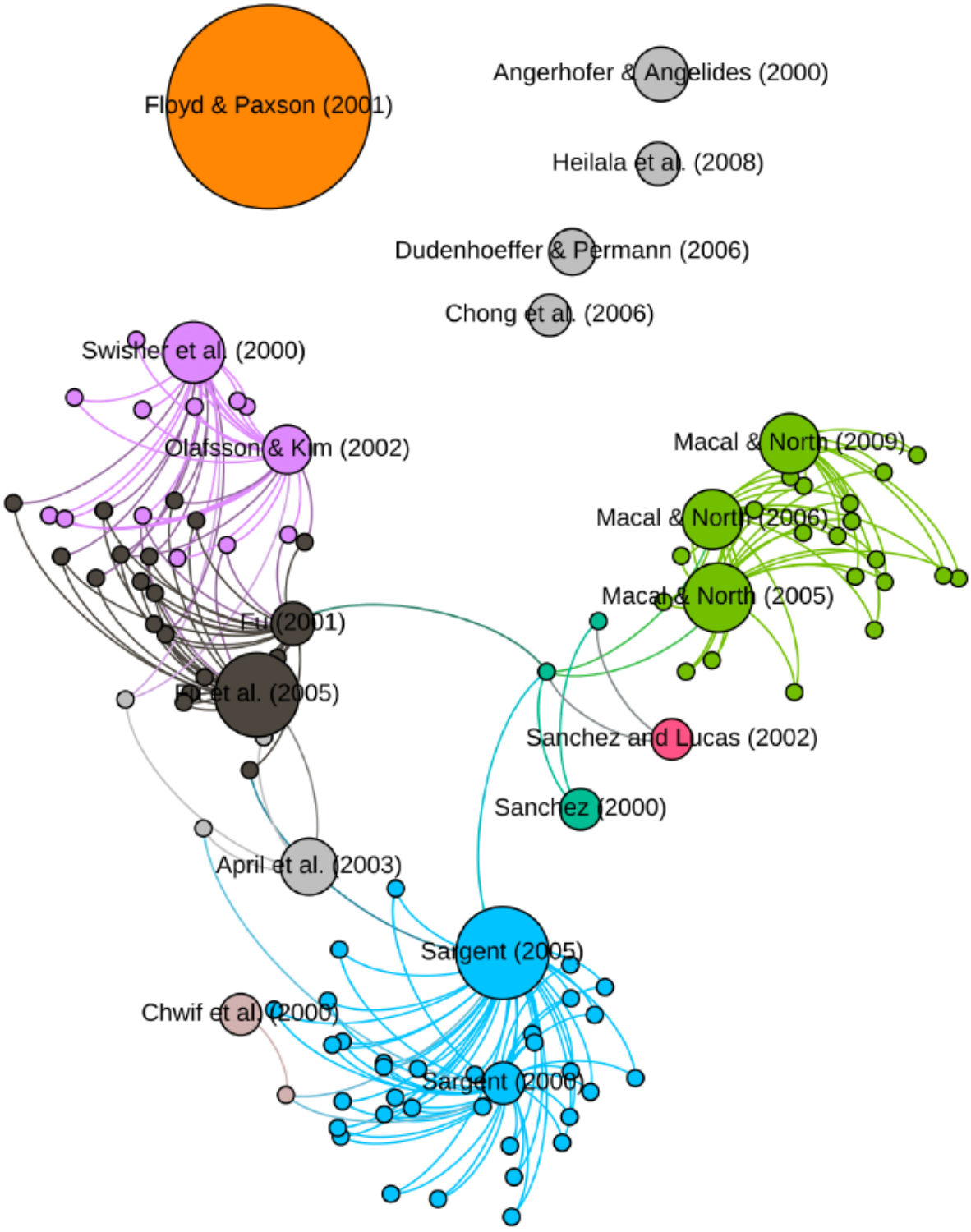

Figure 8: Gephi analysis — WSC network connections of 25 highly cited papers for the period 1990–2014 (node size proportional to number of citations).

example, Table 9 gives details on a length-11 chain between WSC authors James Wilson and Shih-Ping Liu. (In fact, there are many such chains; we simply give one for purposes of illustration.) A piece of friendly advice for Shih-Peng: You can run, but you can't hide from Jim!

Table 9: Jim Wilson's journey through space and time to meet Shih-Ping Liu.*

Author	Jim #	Institution	WSC
James Wilson	0	North Carolina State Univ., Raleigh, NC	—
Peter Lendermann	1	D-SIMLAB Technologies, Singapore	2003
Steffen Straßburger	2	DaimlerChrysler, Ulm, Germany	2007
Richard Fujimoto	3	Georgia Tech, Atlanta, GA	2002
Ioanis Nikolaidis	4	Univ. of Alberta, Edmonton, AB, Canada	1997
SangHyun Lee	5	Univ. of Michigan, Ann Arbor, MI	2011
Vineet Kamat	6	Univ. of Michigan, Ann Arbor, MI	2013
Photios Ioannou	7	Univ. of Michigan, Ann Arbor, MI	2006
Omer Tsimhoni	8	Univ. of Michigan, Ann Arbor, MI	2008
Marcial Lapp	9	Univ. of Michigan, Ann Arbor, MI	2008
Brendan See	10	Univ. of Michigan, Ann Arbor, MI	2010
Shih-Ping Liu	11	Univ. of Michigan, Ann Arbor, MI	2009

*The fourth author (JRW IV) objected to including this table and the related discussion.

5.5 Most-Collegial Authors

WSC is a conference known for its collegiality; and certainly the conference has been instrumental in engendering close relationships among its participants. Some evidence of this is provided by the fact that many WSC-goers have developed extensive networks of collaborators over the years. For instance, Table 10 lists authors who have worked on WSC papers with at least fifty(!) colleagues (covering the period 1968–2015).

It noteworthy that some of the coauthor relationships are especially close. In fact, Table 11 lists coauthor pairs who have jointly written at least 10 WSC papers. These "best friends forever" (BFFs) have maintained relationships than, in some cases, have spanned multiple decades.

6 CONCLUSIONS

The Winter Simulation Conference is the premier discrete-event modeling and simulation conference. The conference has experienced ups and downs over the years — some of which we chronicled — but the trend is up: the quality of the WSC's articles is excellent, and the collegial relationships among the conference participants are strong. In particular, the papers published in the WSC *Proceedings* are highly referenced in various research literatures, and a number of WSC papers have accumulated impressive citation counts. To this end, we presented some simple statistics and interesting facts about the WSC's record in disseminating research within the simulation community. Of course, the WSC is known for its collaborative spirit — so much so that we found a great deal of research interconnectedness among the conference participants. All of this is great news for the WSC's future. And the future is here — WSC 2017 boasts at least 367 terrific, refereed papers that are about to be added to our coffers!

ACKNOWLEDGMENTS

We thank Robert Sargent for his help and many substantive discussions, and Barry Nelson and Eunhye Song for lending us their wonderful list of interesting paper titles.

Table 10: Authors with at least fifty WSC coauthors (1968–2015).

Author	# of Coauthors
James R. Wilson	127
Barry L. Nelson	105
David Goldsman	90
John W. Fowler	80
Simon J. E. Taylor	78
Paul A. Fishwick	74
Lee W. Schruben	72
Richard Fujimoto	68
Luiz Augusto G. Franzese	67
Andreas Tolk	67
Loo Hay Lee	66
Peter Lendermann	65
Adelinde Uhrmacher	65
Marcelo Moretti Fioroni	64
Pierre L'Ecuyer	63
Michael Fu	60
Richard E. Nance	60
Bruce Schmeiser	58
W. David Kelton	54
Jerry Banks	53
Robert G. Sargent	53
Björn Johansson	52
James O. Henriksen	51
Averill M. Law	51

Table 11: WSC BFF coauthors (1968–2015).

Coauthors	# of Papers
Daniel T. Brunner – Thomas J. Schriber	23
Averill M. Law – Michael G. McComas	22
Christos Alexopoulos – David Goldsman	18
Ek Peng Chew – Loo Hay Lee	18
Luiz Augusto G. Franzese – Marcelo Moretti Fioroni	16
Boon-Ping Gan – Peter Lendermann	16
Emily K. Lada – James R. Wilson	15
Natalie M. Steiger – James R. Wilson	15
David M. Ferrin – Martin J. Miller	14
David Goldsman – James R. Wilson	14
Roland Ewald – Adelinde Uhrmacher	13
Osman Balci – Richard E. Nance	13
Michael E. Kuhl – James R. Wilson	13
Charles Macal – Michael North	13
Averill M. Law – Stephen Vincent	12
Christos Alexopoulos – James R. Wilson	11
Wentong Cai – Stephen J. Turner	11
Stéphane Dauzère-Pérès – Claude Yugma	11
John W. Fowler – Gerald Mackulak	11
Boon Ping Gan – Stephen J. Turner	11
David Goldsman – Barry L. Nelson	11
Jan Himmelspach – Adelinde Uhrmacher	11
Emily K. Lada – Natalie M. Steiger	11
Barry L. Nelson – Jeremy Staum	11
Bruce E. Ankenman – Barry L. Nelson	10
Mary Ann Flanigan Wagner – James R. Wilson	10
Fred Glover – James P. Kelly	10
Björn Johansson – Anders Skoogh	10
Jeffrey A. Joines – Stephen D. Roberts	10
Navonil Mustafee – Simon J. E. Taylor	10
Steffen Strassburger – Simon J. E. Taylor	10
Simon J. E. Taylor – Stephen J. Turner	10

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