

A PROFILE OF OR-GIS JOURNAL PUBLICATIONS: HISTORY AND TRENDS

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ABSTRACT

This research collects, synthesizes, and analyzes approximately 300 articles that focus on applications of Geographical Information Systems (GIS) to solve classical and developing problems in Operations Research (OR). We focus predominantly on mainstream OR journals from 1990 to 2010. During this period, we find a generally increasing level of activity in this research stream. However the overall footprint of GIS in OR journals is somewhat negligible. Our findings have implications for OR journals, researchers, and OR/MS curricula.

Keywords: Geographical information systems, GIS, operations research

INTRODUCTION

In recent years, business analytics has been posited as the next frontier of decision sciences (Evans, 2012). Analytics, defined as “the extensive use of data, statistical and quantitative analysis, explanatory and predictive models, and fact-based management to drive decisions and actions” (Davenport & Harris, 2007, pp. 7) is at the forefront of Information Technology (IT) revolution in many organizations. Quantitative analysis, an inherent aspect of analytics, which helps organizations to transform data to information and then proceed from information to insight, is often facilitated by Operations Research (OR). OR methodologies have evolved significantly over decades and now OR can solve large-scale complex problems in many sectors – both in industry and government. OR can provide solutions to problems found in diverse domains – agriculture, aviation, facilities management, healthcare, retail, telecommunications, transportation, utility, etc. to solve problems in capital budgeting, site location, routing and scheduling, supply chain management, resource allocation and distribution, and many other functions. It is important to note that OR problems in several domains and functions contain geographic or spatial elements. For example, problems in vehicle routing have to deal with transportation networks, problems in disaster evacuation and relief have to consider network disruptions, problems in site location have to factor in distances, populations, and geodemographic attributes of the population, problems in agriculture and forestry have to contend with terrain and topology, and problems in public administration have to deal with boundaries of administrative divisions. In fact, an often cited statistic is that almost 80% of all business data is spatial (Pick, 2007). Hence it is natural to expect that the solution of some of the problems mentioned earlier will involve a combination of OR with spatial technologies such as Geographic Information Systems (GIS). Furthermore, the currently ongoing geospatial revolution powered by the Internet (Hall and Partyka, 2008) that provides geo-tagged data at the

fingertips of analysts and data scientists is expected to catalyze the confluence of OR and GIS and facilitate improved analytics. One possible natural outcome is the growth in OR-GIS academic literature and this provides the motivation for our research endeavor.

The overall objective of our work is to understand the current status of OR-GIS research already existing in the literature, investigate previous work done in this arena to identify trends in terms of publication volume, types, methodologies employed, extent of integration of OR with GIS, and use those insights to identify critical knowledge gaps as motivation for future OR researchers.

Before proceeding further, it is important to describe “integration” of OR with GIS. Malczewski (2006) studied integration of GIS with multicriteria decision analysis and has extensively discussed extent of integration and direction of integration. Extent of integration has been classified into four categories: (i) no integration, (ii) loose coupling, (iii) tight coupling, and (iv) full integration based upon differences in how data is input from one system to another, use of a unified data or model manager between two systems and a common user interface, and use of scripting language to create user specified routines within a GIS. Malczewski (2006) has also classified directions of integration into five categories: (i) no integration, (ii, iii) two categories of unidirectional integration with either GIS or its complementary technology (in this case multicriteria decision analysis) as the principal software, (iv) bi-directional integration, and (v) dynamic integration. In bi-directional integration, the flow of data can originate and end in both the GIS and its complementary module. While, bidirectional integration involves onetime flow of information, dynamic integration allows the flow of information between a GIS and its complementary module on a user-specified basis. We adopt the same integration paradigms and their definitions described in Malczewski (2006) due to their appropriateness for our work.

A longer term objective of this research is to also investigate what value does GIS add to the solution of complex large-scale problems in OR. While some sporadic hints exist in the literature, value addition of GIS in OR is not well understood and has not been systematically investigated. Arguably, value added (or perhaps the lack of any value addition) can be established in multiple ways. One approach involves thorough investigation of appropriate literature, extract instances of OR-GIS integration and analyze problems, solutions proposed, costs, benefits, challenges, and the value of GIS integration with OR. Another possible approach involves experimental design; in other words, to construct a series of carefully controlled experiments in various problem areas such as location, routing, etc. and solve multiple small-, medium-, and large-scale instances of problems using appropriate OR methods in non-GIS and GIS-enabled settings. This paper adopts the first approach and attempts to systematically analyze OR-GIS literature as outlined in the following stages.

Stage 1: Conduct extensive literature review guided by best practices in the literature and build database of OR-GIS research articles.

Stage 2: Analyze the historical profile of OR-GIS research articles by studying publication trends in terms of volume, publishing journals, and OR-GIS footprint in journals and temporal changes.

Stage 3: Analyze the geographical profile of OR-GIS research articles by studying author affiliations in an attempt to understand which regions of the world have contributed to the research literature in this field and what factors may have influenced the geographical distribution and possible concentration of authors.

Stage 4: Perform thorough content analysis of articles to understand application domains, types of problems tackled, modeling approaches, solution strategies, correlations between modeling approaches and solution strategies, categories of integration of GIS, the extent of integration of GIS in each category, and benefits, challenges, and costs associated with GIS integration.

Stage 5: Based upon findings from stage 4, investigate the value added (or perhaps a lack of value addition) by integrating GIS with OR.

Stage 6: Based upon findings of stages 2 – 5, attempt to identify research gaps in OR-GIS and outline directions of evolution and growth.

In this paper, we report findings of stage 2 and provide some insights into ongoing work in stages 3 and 4. The remainder of this paper is organized as follows. In Section 2, we describe our literature survey methods. In Section 3, we present findings of our initial investigation of the literature. Section 4 contains implications of our work and Section 5 contains concluding remarks and directions for future research.

METHODOLOGY

In order to examine the current state of research in OR that has integrated GIS, we first conducted a literature review to accumulate a representative pool of refereed journal articles. Steps of the literature survey are outlined in Figure 1. The first step involved selecting a representative set of refereed journals in OR. For this purpose, recently published OR journal rankings (Olson, 2005; Xu, Cheang, Lim, and Wen, 2011) were examined. This is consistent with the journal selection methodology of Jourdan, Rainer, and Marshall (2008). Since the rankings in Olson (2005) and Xu et al. (2011) are reasonably consistent, we selected an initial pool of 33 journals ranked by Olson (2005). The initial list of journals can be found in Appendix A. This initial list is mainly comprised of mainstream OR journals but also includes a few journals with a heavy focus on statistics, operations management, industrial engineering, and manufacturing. Arguably all these disciplines are closely related to OR. Moreover while the focus of the journals (listed in Appendix A) on OR theory and OR practice differs, most are considered to be inclusive in terms of publishing articles that employ OR methodologies as the primary vehicle for problem solving. The second step involved extracting GIS-OR articles from the selected journals. Popular scientific search engines, electronic libraries, and databases such as Ingenta, ProQuest®, ScienceDirect®, and ABI/INFORM were searched using search terms such as “geographic information system”, “GIS”, “geocoding” or variants of the same. The search period spanned 1 January 1990 to 31 December 2010. The search period began in 1990 because faster and cheaper computers, network processing, electronic data clearinghouses, and faster data capture techniques using Global Positioning Systems (GPS) spurred tremendous growth in the advancement of GIS. Furthermore, possibly as a direct outcome of these advancements, the early 1990’s saw the introduction of a popular commercial desktop GIS software. Since our focus was

solely on research articles, any result which was an editorial or a book review was eliminated during the search process.

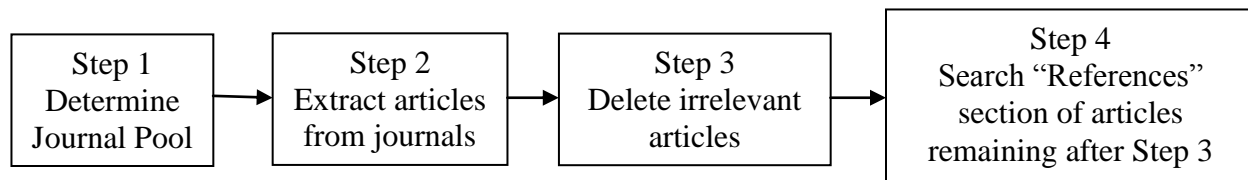


FIGURE 1: STEPS OF LITERATURE SURVEY

Step 3 involved pruning the list of extracted articles. To do so, we used the following criterion: any article that explicitly indicated the use of GIS, or contained substantive remarks about the potential for integration of GIS was retained. In other words, an article which only made a passing reference to GIS in introductory or concluding remarks or did not explicitly use GIS in conjunction with OR was eliminated. This yielded a total of 234 articles spanning 33 journals. Subsequently in step 4, the References sections of all 234 articles were manually searched to identify potential candidate articles in the database of OR-GIS journal publications. While this process is currently ongoing, it has yielded an additional 48 articles spanning 21 additional journals. The list of additional journals can be found in Appendix B and includes journals in OR (ranked outside the top 33 of Olson, 2005), geography and GIS, environmental engineering, information systems, and a couple of other disciplines. Note that these 48 additional articles have all addressed a problem which is formulated as an OR problem and solved using OR methodologies in conjunction with GIS. Further, note that inclusion criterion stated in Step 3 continues to be applicable for these additional articles. At the time of preparing this manuscript, the OR-GIS article database is hence comprised of a total of 282 refereed journal articles published in the period 1990 – 2010 and spread across 54 journals, many of which belong to mainstream OR.

FINDINGS

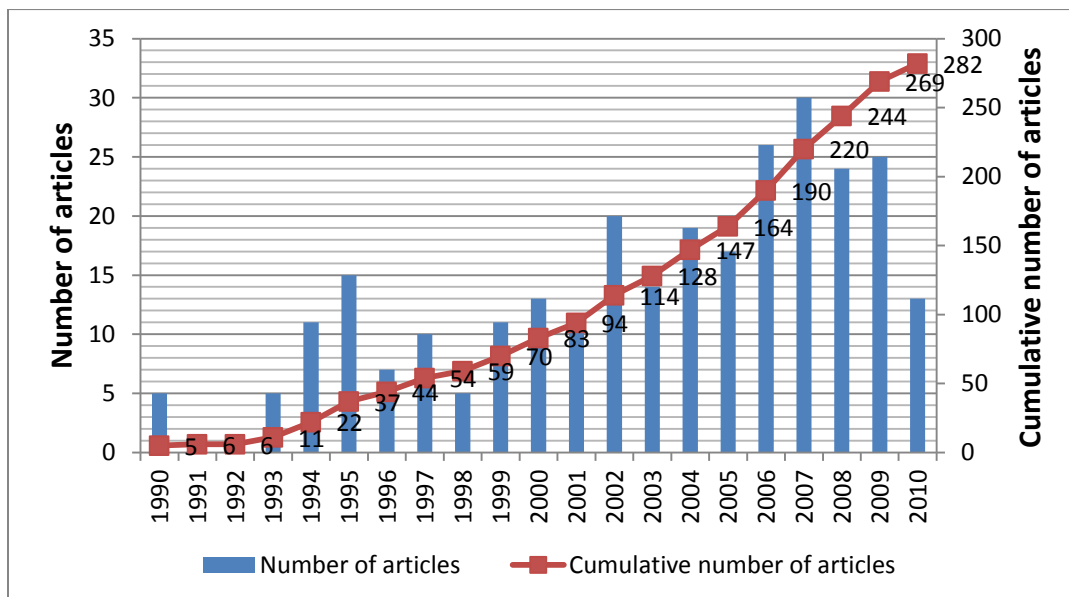
Publication of OR-GIS articles by year

We first report on the general pattern of development of the GIS-OR literature. Table 1 provides the number of refereed OR-GIS articles published annually during the study period of 1990 – 2010 as well as their cumulative totals. Figure 2 shows the cumulative growth of this body of literature. From Figure 2, it is apparent that the growth of this body of literature was moderate in the early 1990s. Of the 282 articles, only 37 papers (or 13.12% of the total) were published between 1990 and 1995.

While Angehrn & Luthi (1990) is one of the earliest papers included in the literature survey, it is pertinent to acknowledge that a very small number of studies prior to 1990 have combined OR with computer-based mapping (not necessarily within a GIS) to solve problems now considered as traditional OR problems such as electoral redistricting (Savas, 1971).

TABLE 1: TOTAL NUMBER OF OR-GIS ARTICLES PER YEAR FOR THE PERIOD 1990 – 2010

YEAR	No. of articles	% of Total	Cumulative	Cumulative % of Total
1990	5	1.77%	5	1.77%
1991	1	0.35%	6	2.13%
1992	0	0.00%	6	2.13%
1993	5	1.77%	11	3.90%
1994	11	3.90%	22	7.80%
1995	15	5.32%	37	13.12%
1996	7	2.48%	44	15.60%
1997	10	3.55%	54	19.15%
1998	5	1.77%	59	20.92%
1999	11	3.90%	70	24.82%
2000	13	4.61%	83	29.43%
2001	11	3.90%	94	33.33%
2002	20	7.09%	114	40.43%
2003	14	4.96%	128	45.39%
2004	19	6.74%	147	52.13%
2005	17	6.03%	164	58.16%
2006	26	9.22%	190	67.38%
2007	30	10.64%	220	78.01%
2008	24	8.51%	244	86.52%
2009	25	8.87%	269	95.39%
2010	13	4.61%	282	100.00%
TOTAL	282			

**FIGURE 2: GROWTH OF GIS-OR LITERATURE FROM 1990 TO 2010**

Every subsequent 5-year period has witnessed steady growth in OR-GIS literature. A growth spurt was witnessed in the period 2001-05; the volume of this literature published during this period almost matched the volume of the previous decade. In fact, approximately 70% of the literature was published in the entire last decade. Table 2 shows the growth of this body of literature for every 5-year segment of the study period (with the exception of 1990 – 95).

TABLE 2: GROWTH IN OR-GIS LITERATURE IN 5 YEAR SPANS

Span	No. of articles
1990 – 1995*	36 (13.12%)
1996 – 2000	45 (16.31%)
2001 – 2005	82 (28.72%)
2006 – 2010	114 (41.84%)
* 6-year span	

In comparison to the growth in GIS-MCDA (Multicriteria Decision Analysis) body of literature which saw approximately 70% (out of 319) articles published during a 5-year span of 2000 – 2004 (Malczewski, 2006), the growth in OR-GIS literature has been rather conservative. It is essential to understand potential reasons for the growth of the OR-GIS literature. As mentioned earlier, user-friendliness of GIS software (Malczewski, 2006) increased gradually through the 1990s with the introduction of desktop GIS. Further proliferation was possible due to the incorporation of classical OR problems such as the shortest path problem within desktop GIS which also happened during the same period. As the usage of GIS in OR became more common, an increasing number of OR journals also started publishing research that incorporates GIS to varying degrees. This is discussed further from a journals' perspective in Section 3.2. As a natural outcome, recognition about the potential of GIS to facilitate decision analysis and provide decision support became wider in the OR community. Lastly, the evolution of decision support systems (Eom and Kim, 2006) along with abundant availability of geospatial data led to the development of spatial decision support systems especially in the last decade. This can partially explain the growth spurt of OR-GIS literature witnessed in the last decade.

It is not a surprise to find that the most productive span in terms of OR-GIS publications have been recent years; the years 2007 followed by 2006 have combined contribute almost 20% of all articles in this body of literature. Since 2007, growth has somewhat slowed and a noticeable decline in the volume of OR-GIS publications was witnessed in 2010. While this decline seems counter-intuitive, it would be interesting to find out if the decline persists or a reversal in trend happens in the initial years of this current decade.

OR-GIS literature from journals' perspective

In light of the growing body of OR-GIS literature, it is important to investigate the extent of diffusion among journals in the OR discipline. As mentioned earlier, our literature survey yielded a total of 282 articles spread across 54 journals. Out of these, six journals did not publish a single OR-GIS article that meets our article selection criterion during the entire study period. Hence 48 journals actually contributed 282 articles. The six journals with no OR-GIS publications are Mathematics of Operations Research, IIE Transactions, SIAM Review, Networks, Journal of Supply Chain Management, and American Journal of Mathematical &

Management Sciences. The first three of these six journals are ranked among the top ten OR journals (Olson, 2005) where the OR-GIS article publications are limited in any case. Table 3 ranks journals (in descending order of number of articles) with at least four OR-GIS articles during our study period.

In terms of yield, the European Journal of Operational Research leads with 41 articles (14.54%) followed by Interfaces, Computers and Operations Research, and Decision Support Systems, each of which has published 24 articles (8.51%) during the study period. These top four most productive journals account for over 40% of the total articles in our survey sample, while the top eight journals account for more than two-thirds of all articles. Alternatively stated, 5% of the journals account for almost one-third of all published articles, while about 15% of the journals have published two-thirds of all published articles.

TABLE 3: REFEREED JOURNALS THAT HAVE PUBLISHED AT LEAST FOUR ARTICLES IN OR-GIS DURING 1990-2010

Rank	Journal Name	Total	Percent	Rank in Olson (2005)
1	European Journal of Operational Research	41	14.54%	13
2-4	Interfaces	24	8.51%	11
2-4	Computers and Operations Research	24	8.51%	27
2-4	Decision Support Systems (and Electronic Commerce)	24	8.51%	29
5-6	Journal of the Operational Research Society	22	7.80%	21
5-6	Mathematics and Computer Modelling	22	7.80%	26
7	Annals of Operations Research	18	6.38%	16
8	Socio Economic Planning Sciences	17	6.03%	NA*
9-10	Omega	10	3.55%	30
9-10	Computers and Industrial Engineering	10	3.55%	32
11	Transportation Science	5	1.77%	9
12-15	Management Science	4	1.42%	1
12-15	Production & Operations Management	4	1.42%	17
12-15	Networks & Spatial Economics	4	1.42%	NA*
12-15	Journal of Geographical Systems	4	1.42%	NA*
	All others	49	17.38%	NA*
	TOTAL	282	100.00%	
* These journals are not ranked among the top 33 OR journals in Olson (2005)				

Consistent with the pattern of growth witnessed in the number of published articles during the study period, the number of refereed journals publishing such research has also consistently grown over the last two decades as shown in Figure 3. The number of journals publishing OR-GIS articles among our original list of the top 33 OR journals (Olson, 2005) and our extended list of 54 journals steadily increased after 2004 and peaked in 2008 at 14 (out of 33, or 42.42%) and 17 (out of 54, or 31.48%) respectively. However the number of journal publishing OR-GIS articles has declined in successive years after 2008 which has clearly impacted the number of

articles published during 2009-10. It remains to be seen if this trend persists or is reversed in the early years of this current decade.

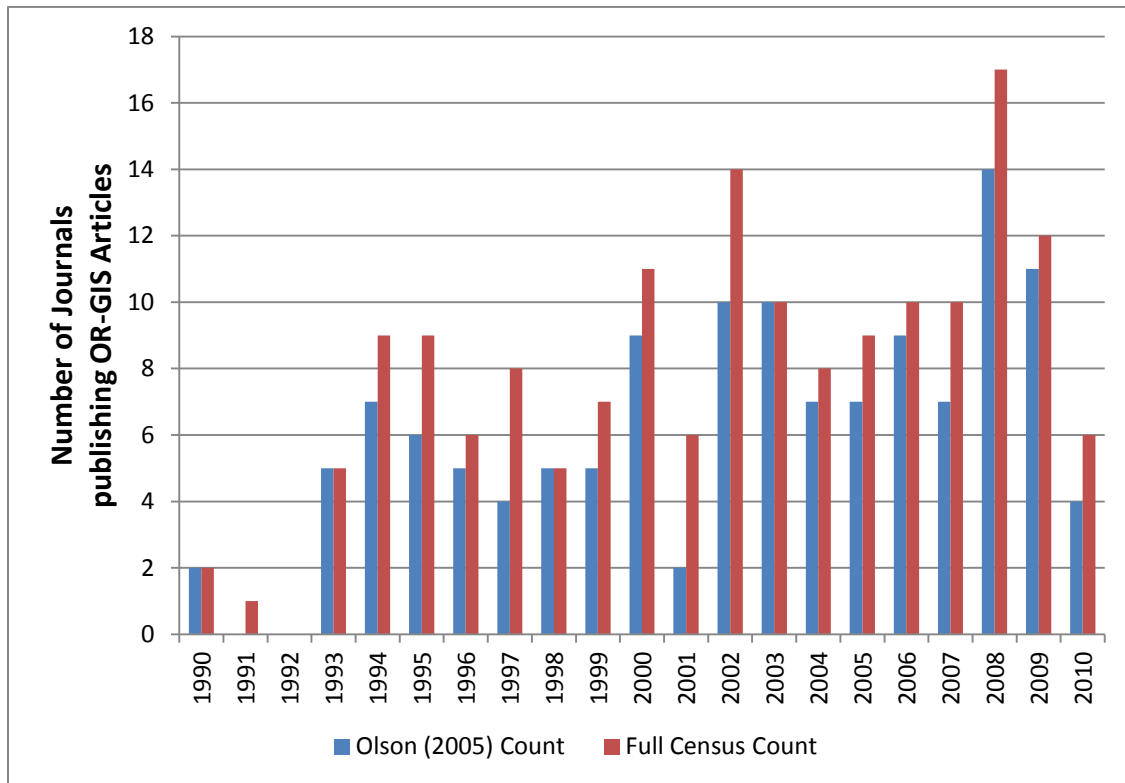


FIGURE 3: NUMBER OF JOURNALS PUBLISHING OR-GIS ARTICLES PER YEAR FROM 1990 TO 2010

Among the top 33 OR journals ranked by Olson (2005), OR-GIS articles have been primarily found in the middle third (journals ranked 12 – 22) and bottom-third (23 – 33). OR-GIS articles are distributed approximately equally between these two categories. In fact these two categories comprised of two-thirds of the top 33 OR journals account for approximately a little over two-thirds of all OR-GIS articles published between 1990 and 2010 as shown in Table 4. In the middle third category, *European Journal of Operational Research* is the runaway leader with 41 articles on OR-GIS. The bottom-third category is jointly led by two journals – *Decision Support Systems* and *Computers and Operations Research* closely followed by *Mathematics and Computer Modelling*. The top third of Olson (2005) journals (ranked 1 – 11) is led by *Interfaces* (ranked eleventh) with 24 OR-GIS articles. This finding is not surprising given the OR practitioner oriented focus of *Interfaces* and the increasing use of GIS in organizations – both business (Blakeley, Bozkaya, Cao, Hall, & Knolmajer, 2003; Camm, Chorman, Dill, Evans, Sweeney, & Wegryn, 1997; Weigel & Cao, 1999) and government (Dekle, Laverie, Martin, Emir-Farinas, & Francis, 2005; Taylor & Vasu, 1999) for analytics and decision-making. It is reasonable to conjecture that the volume of articles published in *Interfaces* would have increased further if organizations – especially those in the business sector had relaxed proprietary concerns about the use of GIS (Pick, 2007) to gain competitive advantage.

TABLE 4: PUBLICATION TREND OF OR-GIS ARTICLES BY JOURNAL RANKING

Journal Ranking	Number of published articles	Percent of overall
Top one-third (Olson, 2005)	41	14.54%
Middle one-third (Olson, 2005)	94	33.33%
Bottom one-third (Olson, 2005)	99	35.11%
Others	48	17.02%

OR- GIS article footprint in journals

It is fairly common for survey articles to provide footprint estimates of a selected topic or area in specific journals. For example, Jourdan, Rainer, and Marshall (2008) compute footprints of business intelligence in ten leading Information Systems journals. Gattoufi, Oral, Kumar, and Reisman (2004) have provided similar estimates for incidence of data envelopment analysis (DEA) during the life cycle of 22 selected major DEA publishing journals. While Gattoufi et al. (2004) have simply provided the number of DEA articles published as an estimate for footprint, Jourdan, Rainer, and Marshall (2008) have computed footprint as the percentage of articles published in a journal addressing a specific topic of interest. This involves obtaining an approximate estimate of the total number of articles published during a study period in a specific journal.

To compute the footprint of OR-GIS, we first computed the exact number of articles published in each journal over our study period 1990 – 2010. This estimate was obtained by conducting an advanced search through the journal publisher's website and considered only articles, short articles, and surveys while eliminating editorials, book reviews etc. over the study period spanning 1990 to 2010. OR-GIS footprint in the top 8 journals with highest number of such articles during our study period is listed in Table 5.

TABLE 5: OR-GIS FOOTPRINT IN TOP 8 MOST PRODUCTIVE JOURNALS (1990 – 2010).

Rank	Journal Name	Total OR-GIS articles	Total number of articles published (1990-2010)	OR-GIS Footprint	Olson (2005) ranking
1	European Journal of Operational Research	41	9132	0.45%	13
2-4	Interfaces	24	1285	1.87%	11
2-4	Computers and Operations Research	24	2744	0.87%	27
2-4	Decision Support Systems (and Electronic Commerce)	24	1647	1.46%	29
5-6	Journal of the Operational Research Society	22	4772	0.46%	21
5-6	Mathematics and Computer Modelling	22	3599	0.50%	26
7	Annals of Operations Research	18	4264	0.40%	16
8	Socio Economic Planning Sciences	17	402	4.23%	Not ranked in Olson (2005)

It becomes expressly apparent that OR-GIS footprint in journals that are part of our literature survey is negligible. Jourdan, Rainer, and Marshall (2008) found that footprints of business intelligence range between 0.83% - 9.00% in 10 leading IS journals; in comparison, OR-GIS footprint in 7 out of 8 most productive journals that have published such research falls below 2% in each of the most productive journals that are ranked in the Olson (2005) study. In fact the journal with the highest percentage footprint of OR-GIS is Socio-Economic Planning Sciences (SEPS) – a journal which is not ranked among the top OR journals in either Olson (2005) or Xu et al. (2011). The relatively high footprint of SEPS is due to its much lower volume of total publications during the study period compared to other journals in Table 5. Another possible reason is the broader scope of the journal that provides an outlet for interdisciplinary research in socio-economic planning and development (naturally amenable to GIS intervention) using quantitative analysis involving OR/MS, statistics, and related arenas. In terms of temporal growth, SEPS again leads the way. Its OR-GIS footprint improved from 2.20% during 1990 – 2000 to 6.86% during 2001 – 2010. This is also true for other journals. For example, the OR-GIS footprint of European Journal of Operational Research (EJOR) improved from 0.22% during 1990 – 2000 to 0.60% during 2001 – 2010. Despite the improvement of footprint in the second decade of this study, overall footprints in all journals listed in Table 5 continue to be very low.

In this article, we propose a more refined method to estimate OR-GIS footprint in journals. The rationale for the refined method is based upon the premise that integration of GIS in OR is more likely in some areas/problems of OR (such as site location, vehicle routing, location-allocation, transportation and logistics, decision support systems, etc) than in others (such as discrete optimization, continuous optimization, inventory control, investment strategy, forecasting, queuing theory, etc). Thus a more realistic footprint of OR-GIS can be obtained by computing the number of such articles in a journal as a fraction of all articles published in areas that are more likely to integrate GIS.

To illustrate this approach, we select EJOR which is the most productive OR-GIS journal in terms of volume of articles published but its OR-GIS footprint is a lowly 0.45% (see Table 5). We first scanned all 41 OR-GIS articles published in EJOR to determine the top three most popular keywords – “decision support”, “location”, and “routing”. Via a quick search conducted using the search engine at the journal publisher’s website, we determined that the number of articles published in EJOR that listed “decision support”, “location”, and “routing” in the Abstract, Title, Keyword fields during 1990 – 2010 is 590, 581, and 385 respectively. Assuming that articles that contain these terms in their Abstract, Title, Keyword fields in EJOR are mutually exclusive, one can quickly compute a “lower bound” for the OR-GIS footprint in EJOR for 1990 – 2010 as 2.63%. This estimate while still low compares much more favorably than the EJOR’s OR-GIS footprint estimate originally computed (0.45%). Admittedly, articles that contain “decision support”, “location”, and “routing” in the Abstract, Title, Keyword fields may not be mutually exclusive. However we have only considered the top three keywords published in 41 OR-GIS articles published in EJOR. Broadening the sample of keywords and journals will help to further refine this approach.

Irrespective of the method to determine OR-GIS footprint in refereed OR journals, it is reasonable to conclude that a significantly wide gulf exists between academia and practice in OR in terms of GIS integration.

Ongoing research

Several stages of this research endeavor are discussed in Section 1. Current work is focused on stages 3 and 4. Stage 3 involves understanding the geographic footprint of OR-GIS articles that were collected as a result of this survey. This is important as a geographic distribution of authors (Katsaliaki, Mustafee, Dwivedi, Williams, and Wilson, 2010) given by authors' national affiliation (Behzadian, Kazemzadeh, Albadvi, and Aghdasi, 2010) will provide clues about dispersion or concentration of expertise in this field. This can potentially impact collaborations and knowledge transfer between authors which is critical for further development of this stream of research. Furthermore, it is expected that geographic distribution of articles may provide insights about the challenges of using GIS to researchers. For example, the process of geocoding addresses in USA is greatly aided by standard address conventions that exist in the country. However the lack of such standards in developing nations in Asia or South America may prove to be a hindrance to the use and integration of GIS in OR in these nations.

Current work in stage 4 is focused on conducting a methodical content analysis of OR-GIS articles following best practices in the literature. This involves thorough examination of every single OR-GIS article along multiple dimensions to determine categories of nature of articles (Jourdan, Rainer, and Marshall, 2008; Katsaliaki et al., 2010), areas of OR-GIS applications (Eom and Kim, 2006; Katsaliaki et al., 2010), kinds of problems studied (deterministic versus stochastic, static versus dynamic, etc.), research strategies and solution methodologies (Eom and Kim, 2006; Gattoufi, Oral, Kumar, and Reisman, 2004), extent of real-world data usage, contributions of GIS, extent of GIS integration with OR and its nature (Malczewski, 2006) and potential challenges encountered. Temporal changes along different dimensions as well as correlations between different dimensions (such as nature of OR problem and research strategy) will also be investigated in this stage of the research. There is a strong possibility that each of dimensions mentioned previously may be somewhat correlated to the value added by the integration of GIS with OR. Developing a deep understanding of the value (if any) added by GIS to the solution of OR problems is the ultimate objective of this research. It is expected that evidence of GIS value addition in OR and a nuanced understanding of the same will motivate researchers and practitioners alike to consider using GIS in conjunction with OR under the correct circumstances.

IMPLICATIONS

In a recent article that analyzes the strengths, weaknesses, opportunities, and threats of the OR/MS ecosystem, Sodhi and Tang (2008) have commented on the need to reinforce the multidisciplinary nature of OR/MS – always considered a key strength of the discipline for finding practical solutions to real-life operational problems. While OR/MS has traditionally drawn on disciplines such as mathematics, statistics, engineering, computer science – often to obtain elegant and powerful algorithms and solutions to complex problems, integration of GIS with OR provides opportunities to open new frontiers for multidisciplinary engagement with disciplines such as geography, public administration, social sciences to name a few. This can facilitate multidisciplinary scholarship involving operations researchers and researchers from other disciplines – always the hallmark of a robust yet evolving discipline.

While recognizing that reliance on mathematics has been a traditional strength of OR, Sodhi and Tang (2008) have identified imbalance of theory and practice in OR/MS journals as a weakness. The findings of this paper – negligible footprint of OR-GIS in top ranked OR journals further corroborate Sodhi and Tang’s contention. The need to exploit vast repositories of data, often spatial in nature to derive geospatial intelligence and facilitate analytics has already led to extensive use of GIS in large organizations. User-friendly cloud-based GIS solutions (software such as ESRI’s ArcGIS Online and Business Analyst Online) will catalyze further growth of the use of GIS – possibly in small- and medium-sized enterprises (SMEs). As opportunities to understand, analyze and propose solutions for real-life complex multi-dimensional spatial problems – possibly using OR and GIS increase, publication avenues will be sought by researchers in academia and practitioners in industry and government. The role of OR journal editors thus becomes crucial as revision of editorial policies, especially of top OR journals will help to redress some of the imbalance between theory and practice in these journals. Disengagement of practitioners, another potential outcome of the imbalance of theory and practice (Sodhi and Tang, 2008) and evident in decreasing presence of practitioners in the editorial boards of journals can also be potentially impacted by the shift in editorial policies. On a related note, editorial support for special issues in OR journals on topics such as OR solutions to geospatial problems can help to somewhat bridge the gap between theory and practice in these journals.

Finally, OR/MS education, particularly in Business schools can be potentially impacted by interdisciplinary research involving OR and GIS. Kerski’s (2007) model of dimensions of GIS education has indicated that teaching about GIS and teaching and learning with GIS will often be facilitated by the development of a rich research agenda in business-related GIS concepts, principles, tools and applications. It goes without saying that Business school graduates who are experts in OR/MS and well versed in geospatial technologies will be much better placed in a competitive job market.

CONCLUSIONS

In this paper, we have initiated preliminary investigations into the issue of value added by integrating geospatial information and technologies such as GIS with OR to solve complex large-scale problems arising in the real world. An in-depth survey of mainstream literature in OR and a few other disciplines such as engineering, forestry, and geography has yielded almost 300 articles spread across 54 refereed journals in the period 1990 – 2010. The focus of this paper is on publications trends observed during this period. We have found that the volume of literature has steadily grown over the last two decades; however the pace of growth during 2001 – 2010 has outpaced the growth witnessed during the 1990s. Reasons for such a growth pattern have been discussed. From a journals’ perspective, we determined that the productivity of journals in the middle- and bottom-third of 33 top-ranked journals in terms of number of OR-GIS published articles is higher than that of the journals in the top-third category. However the overall footprint of GIS in OR journals is somewhat negligible. With an ever increasing focus on analytics in the OR community and the widespread availability of geo-tagged data for mining and gathering geospatial intelligence, opportunities exist for scholars in OR to forge multidisciplinary research collaborations using GIS. This will potentially help to redress the imbalance between research

and practice in OR journals and add to the strength and vitality of OR as a key discipline in analytical problem-solving and decision-making.

APPENDIX A: LIST OF INITIAL JOURNALS

RANK/ID	Olson (2005) Journals	RANK/ID	Olson (2005) Journals
1	Management Science	18	Journal of Combinatorial Optimization*
2	Operations Research	19	Journal of Operations Management
3	Mathematics of Operations Research	20	Decision Sciences
4	Manufacturing & Service Operations Management*	21	Journal of the Operational Research Society
5	Mathematical Programming	22	International Journal of Production Research
6	Journal of the American Statistical Association	23	Journal of Supply Chain Management
7	IIE Transactions	24	Journal of Business Logistics
8	Naval Research Logistics	25	International Journal of Production Economics
9	Transportation Science	26	Mathematical and Computer Modelling
10	SIAM Review	27	Computers and Operations Research
11	Interfaces	28	International Journal of Operations and Production Management
12	Operations Research Letters	29	Decision Support Systems (and Electronic Commerce)
13	European Journal of Operational Research	30	Omega
14	Networks	31	Production and Inventory Management
15	INFORMS Journal on Computing	32	Computers and Industrial Engineering
16	Annals of Operations Research	33	American Journal of Mathematical & Management Sciences
17	Production & Operations Management*		
* These journals did not begin publishing on or before 1 January 1990 when our literature review timeframe commences. The first issue of these journals was published between 1992 and 1999. Since none of these journals have published at least 4 OR-GIS articles during our study period, their impact on this study is minimal.			

APPENDIX B: LIST OF ADDITIONAL JOURNALS (BY DISCIPLINE)

Journal ID†	Journal Title	Discipline	Journal ID†	Journal Title	Discipline
34	Socio Economic Planning Sciences	OR	45	Environment & Planning B	Environmental Sciences
35	Journal of Heuristics	OR	46	Journal of Environmental Engineering	Environmental Engineering
36	Networks & Spatial Economics	OR	47	Integrated Manufacturing Systems	Industrial Engineering
37	INFOR	OR	48	Construction Innovation*	Civil Engineering
38	Transportation Research Part C	OR	49	Geographic Information Sciences	Geography
39	Transportation Research Part A	OR	50	Geographical Analysis	Geography
40	Operations Research International Journal	OR	51	Journal of Geographical Systems*	Geography
41	Risk Analysis	OR	52	Geographical Systems	Geography
42	International Transactions in Operations Research*	OR	53	International Journal of Geographical Information Systems	GIS
43	Information & Management	Information System	54	Transactions in GIS*	GIS
44	Canadian Journal of Forest Research	Forestry			
† Note that unlike Appendix A, Journal ID does not represent the journal's rank in this list.					
* These journals did not begin publishing on or before 1 January 1990 when our literature review timeframe commences. The first issue of these journals was published between 1994 and 2001. With the exception of Journal of Geographical Systems, none of these journals have published at least 4 OR-GIS articles during our study period and hence their impact on this study is minimal.					

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