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Theory and Methodology

Automation, AI and OR: in search of the synergy and publication priorities

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Abstract

Automation is having a profound effect on the way we do work. It is estimated that nearly $40 billion was invested in U.S. industrial automation in 1991, with heavy investment in the European Union and the Asia-Pacific region as well. Some argue that technologies such as microelectronics will lead to widespread structural unemployment and an even greater sector of permanently unemployed. It would seem that OR and AI should be intimately involved in the various decisions that occur over the life cycle of automation technologies. Both of these disciplines share a common heritage and together they could help to improve the benefits reaped from increased usage of automation. In fact both are involved in the automation of decision making to varying degrees. This paper investigates the synergy between automation, AI, and OR using a bibliometric analysis of ABI INFORM citations. Simulation and expert systems were the two methodologies most often found in synergy articles. The results also show that the synergy between these fields has received limited coverage in professional and academic journals. © 1997 Elsevier Science B.V.

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The future of OR is clearly tied to its ability to harness computer technology effectively while devising methods and techniques that will enable organizations to improve productivity and quality. The relationship between OR, computing, and the changing role of technology in the workplace is an important subject that requires investigation. This paper narrows the focus to OR's relationship with one aspect of technology, automation, and one development of the computer revolution, artificial intelligence.

The linkage of OR's future to the computer has been addressed by several authors including Geoffrion (1992) and Harris (1992). In his review of the state of OR affairs, Geoffrion (1992) concludes that the microcomputer and communications revolutions are forces of historic importance to OR. Harris (1992) voices a similar refrain when he discusses the importance of OR's ability to utilize the rapid advancements in computing and information technology creatively.

Of course simply doing a better job of utilizing the computer to provide faster, more powerful, and versatile solution algorithms and methods is a necessary but not sufficient condition for OR to prosper, as both authors indicate. These developments in OR must be linked to organizational improvement in one form or another, since the lifeblood of the profession is its impact on practice. Today's OR analysts and practitioners find most client organizations facing

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pressures to compete on the basis of cost, flexibility, quality and customer satisfaction. These pressures in turn often lead to a focus on eliminating nonvalue enhancing activities and streamlining and downsizing operations. As a result, many organizations are examining critically the role that automation in its various forms plays in the workplace.

The purpose of this paper is to identify some of the key areas of synergy between automation, AI and OR, and to determine the extent to which they are reflected in the publication priorities of professional and academic journals. The next section provides a brief background discussion concerning the reasons for the presumed synergy between automation, AI and OR. The remainder of this paper investigates measures of synergy using a bibliometric analysis of ABI INFORM citations. The results presented may assist editors in reconsidering their publication priorities, and authors in rethinking the direction of their research efforts.

1. Reasons for the synergy

1.1. Automation trends

A few comments on the economic impact and the changing face of automation help to set the stage for the analysis that follows. The economic impact is significant: for example, the U.S. spent nearly $40 billion on industrial automation equipment in 1991 across a wide range of industries (see also the Industrial Automation Investment Profile, National Electrical Manufacturers Association, (1991). Across five major industry groups which employ more than 40 percent of all manufacturing employees, nearly three out of every four plants use advanced manufacturing technology (Bureau of the Census (1990)). The development of a strong electronic sector that includes significant investment in automation is strategic for the development of the overall EC economy (European Commission, 1994). The aggregate impact of automation on worldwide employment is difficult to measure, but some argue that technologies such as microelectronics will lead to widespread structural unemployment and an even greater sector of permanently unemployed (Gottinger, 1990).

Automation is a rapidly evolving technology rooted in, but not limited to, manufacturing. From the viewpoint of manufacturing engineering, automation is "a technology concerned with the application of mechanical, electronic and computer based systems to operate and control production" (Groover, 1987). However, the scope of automation has expanded to include information collection and processing, process control, and communication links with the outside environment. This expansion is directly related to the force in computing and communications that Geoffrion (1992) articulates.

The expanding role of automation is also related to the development of automated reasoning systems. For example, developments in machine learning, heuristics and knowledge based systems are having an increasing impact on the scope of automation activities. All of these subjects are of keen interest to OR and/or AI professionals. Today we are moving towards building a high autonomy system that is "an intelligent, realtime system with selfdetermination capability for carrying out predefined objectives over an extended period of time in an uncertain environment" (Kim and Chung, 1991).

To better understand the potential synergy of OR and AI with automation, we need a broader definition of this quickly changing field. Automation can be defined as "a technology which minimizes various costs incurred by both routine physical labor and routine human intellectual reasoning, by designing and building machines which perform human desired operations with minimal or no human intervention. These machines should be as selfactivated, selfacting, selfdetermining, selfregulating, and selfreliant as is practical or necessary" (Liberatore, 1996). This definition highlights the importance of the two major trends discussed above: the increasing role of computers and communications, and automated reasoning.

1.2. OR and AI synergy

What about the synergy between OR and AI? The Committee on the Next Decade in Operations Research (CONDOR) proposed a set of research topics suggestive of possibilities that could arise from the integration of OR and AI. CONDOR stated that both disciplines focus on effective problem solving and decision making: OR uses algorithmic, mathematically based approaches, while AI uses expert knowledge and heuristics (CONDOR, 1988).

Similar points are raised by several authors including Simon (1987) and Grunwald and Fortuin (1989). Simon (1987) begins by discussing the common origins of OR and AI, and then suggests that OR's impact could be enhanced by incorporating AI tools within our profession. Grunwald and Fortuin (1989) argue that OR can increase its strategic impact on organizations and society by playing a leading role in the development of decision support systems (DSS) and expert systems (ES). In promoting the synergy between OR and AI, Simon (1987) urges us not to take a traditional discipline oriented approach to problem solving. This is especially appropriate when we are dealing with an important, evolving field like automation. "We must let the problem that we are trying to solve determine the methods we apply to it, instead of letting our techniques determine what problems we are willing and able to tackle" (Simon, 1987). OR should consider enlarging its algorithmic based paradigm (Grunwald and Fortuin, 1989).

1.3. Some examples of OR synergy with automation and AI

What are some of the actual or potential areas of synergy? Singhal et al. (1987) argues that the role of OR in manufacturing automation can be categorized according to the several phases that occur over the system life cycle: technology choice; physical systems design; design of the production planning, scheduling and control system; installation and startup; and steady state operations and improvements. In each of these phases there are ample opportunities for synergy between automation, AI and OR. For example, expert systems are increasingly being combined with OR approaches in such areas as the planning and scheduling of flexible manufacturing systems (FMS). AI can help to develop new models in situations where a portion of the knowledge about operations is illspecified and qualitative.

In services and administrative activities, automation often is associated with efforts to computerize and reengineer business processes. Important applications include streamlining standard office tasks, such as accounts payable or billing, or improving transactions processing, such as loan granting or insurance claims. New technologies such as electronic imaging and optical character recognition (OCR) are having a major affect on work flow automation. Many of the OR application areas that were described as part of the system life cycle for manufacturing automation by Singhal et al. (1987) are equally applicable to new office automation technologies such as electronic imaging. It would seem that there would be ample opportunities for synergy between OR and AI in nonmanufacturing automation as well.

2. The study

A bibliometric analysis of ABI INFORM was conducted to uncover any emerging publication trends or findings relative to the relationship and synergy between automation, AI and OR within the business sector. ABI INFORM is a collection of abstracts from more than 800 business publications of which approximately 400 are classified as academic, 300 general business, and 100 trade publications. General business and trade publications were included as part of the analysis reported here since they serve as an outlet for some applied research and also report on emerging trends. Also, the assignment of specific journals to one of the three categories may be somewhat arbitrary.

Two important assumptions about the ABI INFORM collection of abstracts are required before proceeding further. First, it is assumed that the topical coverage of the ABI INFORM collection of publications is representative of the general activities and interests of OR and AI business oriented researchers and practitioners, and that automation is covered in sufficient detail from a business perspective. This is a reasonable assumption, since a review of the ABI INFORM publication list indicates that nearly all major English language business publications are included. Also, because of the inherent lags between initiating and completing research and consulting studies, the five year period 1987–1991 was analyzed. This time frame generally covers activities in the second half of the 1980's, a period of accelerating developments in applied AI and automation. Second, it is assumed that the abstracts (including article titles and ABI INFORM terms) sufficiently reflect the themes of the indexed articles. However, since this study did not include conducting a detailed content analysis of each abstract, this issue does not appear to be a major concern.

A structured query approach was used to guide the search activity. This method was used to identify the articles covering two or more subjects of interest. For example, consider the search process for articles covering all three subjects of interest in this paper: automation, AI and OR. When searching ABI INFORM using "automation and artificial intelligence and (management science/operations research)" no entries will be found (which is shown later not to be the case). The structured query approach is based on the fact that one subject addresses many topics, and one topic covers many subtopics, and so on. For example, an article discussing computer integrated manufacturing (CIM), expert systems, and simulation falls within the intersection of all three subject areas and should be selected. Thus, the key to applying the structured query approach is the selection of a group of keywords that help to define each of the three subject areas.

As applied in this research, each "subject tree" had two or more levels: the subject name (e.g., MS/OR) and specific keywords within each subject or subtopic (e.g., linear programming). These keywords are not meant to be exhaustive, but reflect important topics within each area. Additional keywords other than those reported here were searched initially, but were eliminated because their connection to the specific subject was somewhat nebulous. For example, "systems analysis" and "heuristics"

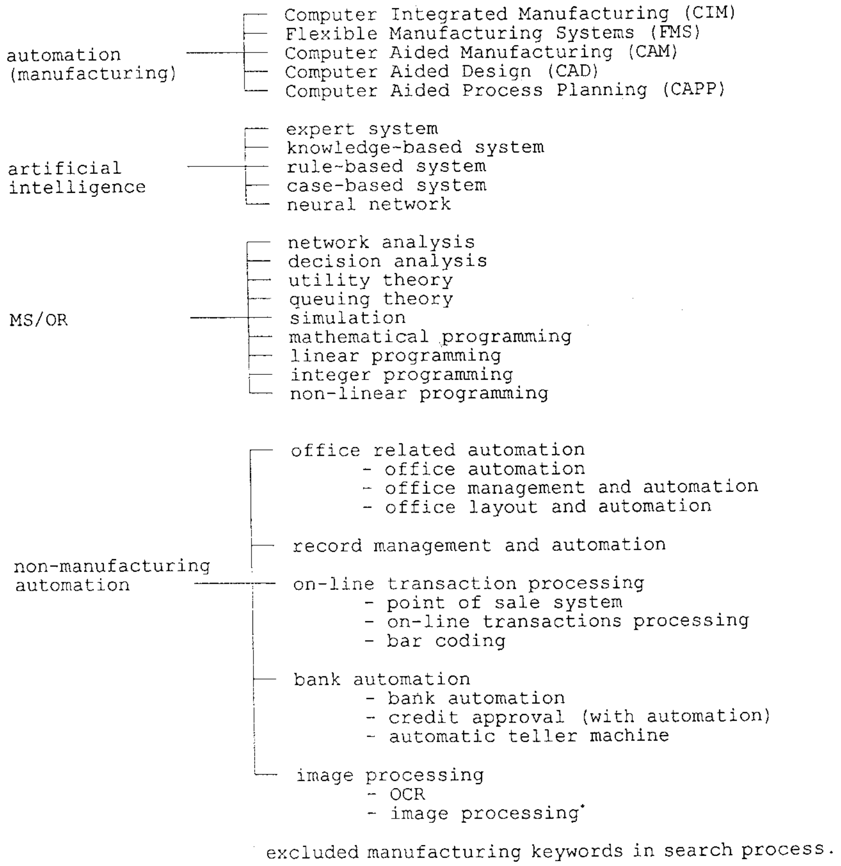

Fig. 1. Subject trees used for structured query search for automation, AI and OR.

Table 1
Summary statistics of selected automation, AI and OR abstracts

	Year					
Category	1987	1988	1989	1990	1991	Total
AUTO	455	644	672	657	632	3060
AI	413	458	405	427	406	2109
MS/OR	822	1033	996	1023	990	4864
N-M[a] AUTO	713	666	588	541	688	3196

[a] NONMANUFACTURING.

are too general and could relate to OR, AI or other problem solving activities.

A number of issues arose in trying to develop a relatively small number of keywords to define the OR subject category. Although OR uses algorithmic, mathematically based approaches, it embodies more than a collection of techniques. However, as a first step in a study of synergy, OR articles were defined as those developing or applying one of several key techniques that most academics and practitioners alike normally associate with this field.

We also note that the automation category was analyzed for both manufacturing and nonmanufacturing activities. Identification of specific technologies attributed primarily to nonmanufacturing automation required a detailed analysis of ABI INFORM coding categories. The nonmanufacturing automation subject tree is the first attempt known to the author of categorizing activities in this area. An analysis of coding categories also led to the final set of AI keywords.

With these qualifications in mind, Fig. 1 shows the subject trees used. Thus, an abstract was selected for a given subject area if it contains at least one of the keywords in its subject tree. For example, if an abstract contains the keyword "expert system" it was counted under the "artificial intelligence" category, regardless of the other keywords it might contain. For each abstract selected, a vector was created to indicate which of the keywords from each of the subject trees given in Fig. 1 are present. A synergy article contains one or more keywords from the subject trees of interest, such as MS/OR and automation. In addition, synergy articles relating to specific keywords in two subject trees were also determined, such as "expert systems" and "simulation." The necessary tabulations and crosstabulations of the vectors were accomplished using SAS as described in the next section. The results present some interesting insights concerning the synergy between automation, AI and OR as reflected in ABI INFORM citations.

3. The results

Following the initial jump from 1987 to 1988, the total number of abstracts selected using this search procedure was fairly constant over time for all but the nonmanufacturing automation category (Table 1). After a decline in 1989 and 1990, the number of abstracts selected in the nonmanufacturing automation category rose back to the 1988 level. This analysis provides an indication that overall interest in the categories remained roughly constant over the 1988–91 period, although there could be a changing mix of journals covering these topics (the latter are difficult to analyze because of the lack of a definitive classification of the journals covered by ABI INFORM as previously mentioned).

3.1. Synergy indicators

Table 2 summarizes the number of articles having at least one keyword from two or more categories. These data can be thought of as macro level indicators of synergy. The largest synergy indicator occurred between OR and manufacturing automation, as one might expect. Note that on a percentage basis all of these measures of synergy are quite small, especially those concerning nonmanufacturing automation. Also note that each indicator actually *declined* in all cases from 1990 to 1991. Surprisingly, only 17 articles, or about 0.18% of the total selected over the five year period, had at least one keyword from the manufacturing automation, OR and AI cate-

Table 2
Category synergy of selected abstracts

Synergy	Year 1987	1988	1989	1990	1991	Total
AUTO and OR	34	56	46	54	39	229 (7.48%, 4.71%) [a]
AUTO and AI	30	29	25	33	18	135 (4.41%, 6.40%) [a]
OR and AI	21	31	38	37	30	157 (3.23%, 7.64%) [a]
AUTO and OR and AI						17 (0.56%, 0.35%, 0.81%) [b]
N–M AUTO and OR	7	9	8	7	6	37 (1.16%, 0.76%) [a]
N–M AUTO and AI	19	11	27	21	17	95 (2.97%, 4.5%) [a]
N–M AUTO and OR and AI						5 (0.16%, 0.10%, 0.24%) [b]

[a] Total expressed as percentages of selected abstracts from each category.
[b] Total expressed as a percentage of total selected abstracts across all categories.

Table 3
Number of abstracts indicating synergy between MS/OR and manufacturing automation keywords (1987–1991)

MS/OR keywords	Manufacturing automation keywords FMS	CAM	CAD	CIM	CAPP	Total
Simulation	38	51	126	47	2	208
Other [a]	16	4	7	3	0	29
Total [b]	49	54	132	48	2	229

[a] Includes linear programming, mathematical programming, nonlinear programming, integer programming, queuing theory, decision analysis, utility theory, and network analysis.
[b] More than one MS/OR keyword could be present in an abstract.

Table 4
Number of abstracts indicating synergy between AI and manufacturing automation keywords (1987–1991)

AI keywords	Manufacturing automation keywords FMS	CAM	CAD	CIM	CAPP	Total
Expert system	12	29	65	53	6	121
General AI [a]	5	8	33	17	3	66
Other [b]	5	4	12	13	1	28
Total [c]	19	40	103	76	10	135

[a] The keyword AI is mentioned only; i.e., no specific AI is mentioned.
[b] Includes knowledge based (systems), rule based (systems), case based (systems), and neural networks.
[c] More than one MS/OR keyword could be present in an abstract.

Table 5
Number of abstracts indicating synergy between MS/OR and AI keywords (1987–1991)

MS/OR keywords	AI keywords			
	Expert system	Neural network	Knowledge based [a]	Total
Simulation	97	25	9	125
Other	25	2	6	26
Total [b]	114	26	13	144

[a] The rule based and case based keywords provided no synergies.
[b] More than one MS/OR keyword could be present in an abstract.

gories. The corresponding result for nonmanufacturing automation, OR and AI is even smaller, namely, five articles.

What is the specific nature of the synergy across categories? Tables 3–6 illustrate the most frequently occurring keywords across the intersections of OR, AI and automation categories. The key findings can be summarized as follows:

Table 6
Synergy indicators for nonmanufacturing automation: 1987–1991

	No. of abstracts
OR and nonmanufacturing automation	
Simulation	34
Total OR group	37
AI and nonmanufacturing automation	
Expert system	72
Total AI group	95

1. Simulation is by far the OR technique that is found to occur most frequently in conjunction with any of the manufacturing automation keywords (see Table 3);
2. Expert systems is the dominant AI technique that occurs most frequently in conjunction with any of the manufacturing automation keywords (see Table 4);
3. Simulation is the OR technique which is most often found in conjunction with AI techniques, with the biggest intersection occurring with expert systems (see Table 5).
4. Concerning nonmanufacturing automation, simulation and expert systems are the dominant techniques in terms of synergy (Table 6).

Taken together these results suggest that simulation and expert systems are the key points of synergy across the OR, AI and automation categories. The lack of reported articles covering mathematical programming topics in conjunction with automation is somewhat surprising.

Table 5 also indicates a significant synergy between neural networks and simulation. It is interesting to note that the number of abstracts in the ABI INFORM database containing the keyword "neural network" has grown from only five in 1987 to 66 in 1991. Taken together, these two findings suggest another growing area of synergy between AI and OR. A detailed examination of the neural network abstracts first with, and then without, the presence of OR keywords might provide some interesting ideas

Table 7
Journals publishing manufacturing automation synergy articles: 1987–1991

	No. of abstracts	
	AI and OR	AUTO and OR
Computers and Industrial Engineering	21	27
Computers and Operations Research	3	0
Decision Sciences	3	2
Decision Support Systems	9	0
European Journal of Operational Research	11	9
Industrial Engineering	1	11
Interfaces	8	3
Journal of the Operational Research Society	13	1
Management Sience	0	1
Mathematics of Operations Research	0	0
Operations Research	0	0

for future work (this is left to the interested reader!). Of course, the same approach could be applied to other emerging areas as well.

Which journals publish synergy articles? Table 7 indicates the extent to which some wellknown OR and related journals publish manufacturing automation synergy articles. The lack of coverage by some leading OR journals is noteworthy. For nonmanufacturing automation, *no* synergy articles were found for any of the journals listed in Table 7. Hopefully, the later result indicates that OR efforts in the nonmanufacturing automation arena had not yet reached publication stage.

4. Conclusions / implications

The prominence of simulation and expert systems as the key indicators of synergy leads to some speculation concerning the types of modeling approaches that are most frequently applied in automation studies. First, both of these modeling approaches are very *flexible*, in terms of how they represent knowledge and data and their interrelationships. Second, both of these approaches are *easily understood* at some level by most users. Third, both approaches can be combined with other methods (mathematical programming, neural networks, etc.) as needed to properly model the situation at hand, enabling the development of *hybrid models*. It is in the development of hybrid models where the synergy between OR and AI might be most effective.

Given the macro measures of synergy reported here, it appears that academic journals may not be publishing enough "cutting edge" research on the development or application of hybrid models or related topics as applied to automation. Of course, there could be several reasons for this: lack of research in these areas, a dearth of good quality articles, or publication priorities. Perhaps all three apply to some extent. Perhaps there is less publication interest in these topics since they do not represent "pure" modeling paradigms nor yield elegant models and solutions.

The results previously presented seem to indicate that OR and AI professionals should place added emphasis on publishing synergistic research in our academic journals. For example, the impact of business process redesign or reengineering studies should offer additional opportunities for conducting synergistic research, especially using flexible modeling tools. Future research studies in this area should be conducted to determine if the advances in AI have contributed to increased synergy with automation and OR. The interest in automation expressed by many organizations shows no sign of abating, with rapid growth in the nonmanufacturing sector underway.

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References

Bureau of the Census, "Statistical brief: advanced manufacturing technology SB-13-90", U.S. Department of Commerce, Washington, D.C., 1990.

CONDOR, "Operations research: the next decade", *Operations Research* 36 (1988) 619–637.

European Commission, "Panorama of EU industry 1994", Section 10: Electronic Engineering, 1994.

Geoffrion, A.M., "Forces, trends, and opportunities in MS/OR", *Operations Research* 40 (1992)423–445.

Gottinger, H.W., "The impact of micro-electronics on employment: an international techno-economic assessment", *International Journal of Technology Management* 5 (1990) 317–336.

Grunwald, H.J., and Fortuin, L., "DSS and ES in the 'information organization'—back to the roots of OR", *European Journal of Operational Research* 41 (1989) 142–150.

Harris, C.M., "Computers and operations research: a marriage for growth", *Operations Research* 40 (1992) 1031–1039.

Kim, T.G., and Chung, M., "Embedding simulation modeling in development of high autonomy systems", Proceedings of the Second Conference on AI, Simulation and Planning in High Autonomy Systems, 1991.

Liberatore, M.J., "Automation", in: C. Harris and S. Gass (eds.), *Encyclopedia of Management Science and Operations Research*, Kluwer Academic Press, 1996, 28–31.

National Electrical Manufacturers Association, "Industrial automation investment profile", Washington, D.C., 1991.

Simon, H.A., "Two heads are better than one: the collaboration between AI and OR", *Interfaces* 17/4 (1987) 8–15.

Singhal, K., Fine, C.H., Meredith, J.R., and Suri, R., "Research and Models for Automated Manufacturing", *Interfaces*, 17/6 (1987) 5–14.