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In 1986, Bodily stated that practitioners could use spreadsheets to model management science/operations research (OR/MS) problems. We surveyed OR practitioners to determine the extent of implementation of these OR/MS problems in a spreadsheet environment and found that end users are solving OR/MS problems using spreadsheets across many functional areas of business, though in varying degrees. Some areas show higher use than others and spreadsheet models are being used to implement various OR tools in a pattern very similar to their use in the nonspreadsheet environment.

Bodily [1986] stated that end users were adopting spreadsheets as a decision-making aid because they provide a natural interface for model building, they are easy to use in terms of inputs, solutions, report generation, and they allow users to perform what-if analyses. He continued that, because of these key properties, end users could use the spreadsheet to solve operations research/management science (OR/MS) problems and to improve decision making.

We conducted a survey to determine to what extent Bodily's observations have been implemented, particularly in view of the rapidly evolving spreadsheet technology. Are practitioners indeed using spreadsheets to solve OR/MS problems and, if so, under what circumstances? We sent a questionnaire to OR practitioners to determine what industries have accepted and are using spreadsheets for OR/MS problems and to identify the most common functional areas and the OR/MS tools

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used. We examined the perceived benefits and limitations of spreadsheets as characterized by practitioners in an effort to understand the circumstances in which spreadsheets have not been accepted and the circumstances in which the end users have used OR/MS methods and tools in the spreadsheet environment.

The literature contains several examples of implemented spreadsheet applications. The OR/MS tools used in these successful implementations include the analytic hierarchy process [Liberatore 1988; Mustafa 1989], decision trees [Parlar 1990], forecasting [Miller and Liberatore 1989], interactive multicriterion optimization [Troutt, Tadisina, and Clinton 1991], inventory analysis [Bookbinder, McAuley, and Schulte 1989; Tyworth 1991], linear and integer programming [Pirlot 1990], and simulation [Mendoza et al. 1991; Oren and Smith 1992]. These spreadsheet models were used in quite diverse application areas, from production and manufacturing to financial and forestry management. Several authors described how spreadsheets facilitated the integration of two or more management science models, for example, integer programming and simulation [Eppen, Martin, and Schrage 1989], linear programming, network analysis, and statistical models [Walton 1989], or inventory analysis and simulation [Mendoza et al. 1991].

The literature contains many discussions on the virtues and benefits of the spreadsheet environment. Spreadsheet models provide a widely understood format, they have a more natural interface than algebraic models, the final users are often the model builders who therefore have greater confidence in the models, model generation and solution procedures are readily integrated, and they offer DSS facilities and automatic what-if analysis [Pirlot 1990; Roy, Lasdon, and Plane 1989; Vazsonyi 1993; Walton 1989]. However, in spite of the documented successes, the use of OR/MS tools in spreadsheets is not appropriate for all cases and the everyday use of hitherto specialized tools by end users is not without some reservations. Spreadsheets may be perceived as too limited or too slow for large or complex applications, or such applications could require excessive (macro) programming to be implemented in the spreadsheet. Indeed, it may simply be easier to use an established specialized package rather than a spreadsheet for certain types of problems. While many authors extol the virtues of spreadsheets, some at the same time warn that certain applications are predisposed for spreadsheet treatment and others are not (for example, Freeman [1993]). Several authors stress that the strengths of these approaches are the decision-aid as opposed to the decision-making aspects [Pirlot 1990; Roy, Lasdon, and Plane 1989]. Another concern is that the powerful tools now potentially at the end users' disposal may undervalue the simple tool for the simple task [Berry 1989].

Given these advantages and disadvantages and bearing in mind the widespread availability, comparative low cost, high performance, and desirable features of spreadsheets, we focused on OR practitioners to determine the extent of the use and acceptance of spreadsheets for their operations research/management science models.

The Survey Method and a Profile of Respondents

To understand the extent to which practitioners are using spreadsheets to model OR tools, we designed a questionnaire to collect data about the types of spreadsheet and nonspreadsheet models that they develop and use in practice. We collected two sets of data; one describes spreadsheet-based OR/MS models and the other describes nonspreadsheet-based OR/MS models.

We designed the survey for practitioners with diverse OR/MS exposure and knowledge, from the OR specialist and consultant to the manager who might build an occasional OR/MS model to support decision making. To ensure, however, that the practitioners sampled had some minimal understanding of OR/MS, we acquired a list of 1,467 US practitioners from the *INFORMS Membership Directory* and the names of another 361 US practitioners from the list of the Production and Operations Management Society. We randomly selected no more than one name from any given organization to be included in the sample to ensure that the same model was not described by two sampled individuals.

We mailed the questionnaire to 760 of these practitioners from the total list. We asked them to identify their organization's industry and the number of spreadsheet- and nonspreadsheet-based OR/MS models used in their organization. We received 96 usable responses—a response rate of 12.6 percent. We recognize the possibility of a nonresponse bias as a result of the low response rate, but this is quite common in studies of this nature. The respondents are associated with quite diverse industries, which reduces the effect of low response rate bias. Small, medium, and large organizations are approximately evenly represented in the sample (Table 1).

Overall, the respondents reported developing over twice as many models in the nonspreadsheet environment as in the

	Size of Firm			Respondents	
Industry	Large (>1000)	Medium (100–1,000)	Small (<100)	Total	Percentage
Manufacturing and services	14	11	11	36	38%
Consulting	1	4	7	12	13%
Information systems	2	3	6	11	11%
Miscellaneous	3	3	4	10	10%
Transportation	7	0	3	10	10%
Government	2	3	3	8	8%
Health services	2	3	0	5	5%
Utilities	2	1	1	4	4%
Total	33	28	35	96	100%

Table 1: The table shows the number and percentage of industries represented by the respondents of the survey. The firms of the respondents are classified as large, medium, or small according to whether the total number of employees is greater than 1,000, between 100 and 1,000, or less than 100.

Industry	Total		Average Number of Models per Organization	
	Spreadsheet Models	Nonspreadsheet Models	Spreadsheet Models	Nonspreadsheet Models
Manufacturing and services	171	470	4.75	13.06
Consulting	110	152	9.17	12.67
Information systems	25	59	2.27	5.36
Miscellaneous	42	84	4.20	8.40
Transportation	8	95	0.80	9.50
Government	50	70	6.25	8.75
Health services	10	11	2.00	2.20
Utilities	6	6	1.50	1.50
Total	422	947		

Table 2: The table shows the number of models in the 96 responding organizations which use OR/MS tools implemented in either spreadsheet or nonspreadsheet environments.

spreadsheet environment (Table 2). For large organizations, 19 percent of all implementations are in spreadsheets as opposed to 42 percent and 43 percent for medium and small organizations, respectively.

The transportation industry has a much lower use of spreadsheet models than the other industries (Table 2). A total of 18 respondents reported no spreadsheet models, and of these, five were in transportation. This means that of the 10 respondents sampled in the transportation industries, half did not use spreadsheets for their models. These five respondents did, however, contribute 54 of the 95 nonspreadsheet models described.

From the responses of the 96 practitioners, we constructed a database describing 189 spreadsheet-based OR/MS models and a database describing 200 nonspreadsheet-based OR/MS models. Although Table 2 shows more models, not all of these are included in our databases. To encourage response, we asked the respondents to select and describe in detail only a limited number of spreadsheet and nonspreadsheet models at their organizations. For each model that they chose to describe, we asked them to identify the OR tools employed in the model and the functional application areas it addressed. To compile the complete list of standard OR tools and functional areas that we asked them to consider, we used the tools and functional areas list from the *International Abstracts of OR* and supplemented it with others we considered applicable.

Four main issues were the focus of the survey, (1) Are spreadsheet models used to implement OR/MS tools in a pattern similar to or different from nonspreadsheet models? (2) In what functional areas are spreadsheets being used? (3) What are the OR/MS tools being applied in various functional areas? (4) Are the OR tools being integrated with each other more in the spreadsheet environment than in nonspreadsheet environments?

The Profile of OR Tools

OR tools are used in 189 spreadsheet and 200 nonspreadsheet models (Figure 1). Since each of these models could involve using multiple tools, there are a total of 313 OR tools for spreadsheet applications and 394 OR tools for nonspreadsheet applications. In general, there is considerable consistency of use of OR tools between the spreadsheet and nonspreadsheet models. The most popular tools for both spreadsheet and nonspreadsheet models are decision support systems (DSS), forecasting, linear programming, simulation, and statistics. This is consistent with studies by Cornford and Doukidis [1991], Forgionne [1983], and Ledbetter and Cox [1977]. The data illustrate a general acceptance of the use of spreadsheet models consistent with the implementation of OR tools at large.

The Profile of Functional Areas

To determine the level of penetration of spreadsheet models across functional areas, we calculated the percentage of spreadsheet penetration for each functional area (Figure 2). Based on these percentage penetration values, we found that the functional areas tend to align into three distinct groups (Table 3). Spreadsheets are well represented and used across all functional areas.

The lowest use of spreadsheet models is in facilities and transportation, manufacturing, and research and development (R&D) (Group 1). These could be considered the traditional OR application areas in

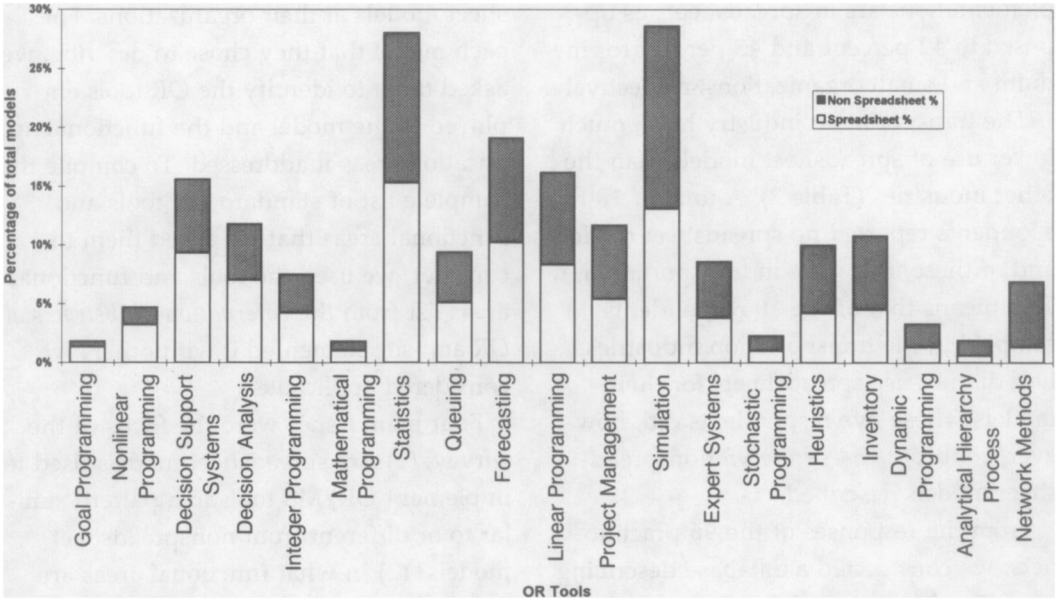

Figure 1: The OR tools arranged in decreasing order of the ratio of percentages between spreadsheet and nonspreadsheet models show that OR tools are being used in the spreadsheet environment. The nonspreadsheet percentage is equal to the number of nonspreadsheet models using the OR tool divided by the total number of nonspreadsheet models. The spreadsheet percentage is equal to the number of spreadsheet models using the OR tool divided by the total number of spreadsheet models.

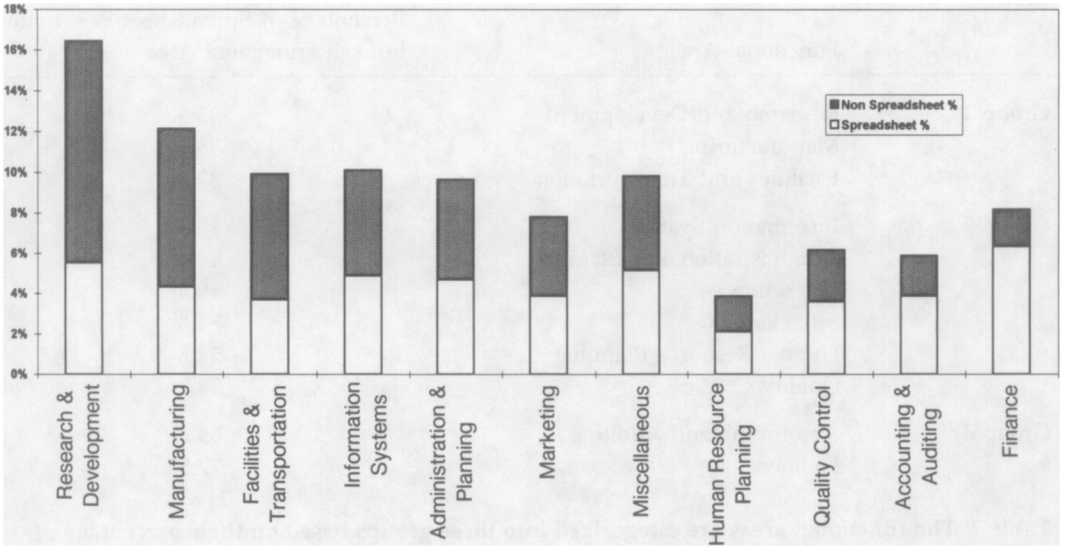

Figure 2: The percentage of total spreadsheet and nonspreadsheet implementations across 11 functional areas shows acceptance of spreadsheets across all functional areas. The nonspreadsheet percentage is equal to the number of nonspreadsheet models in each functional area divided by the total number of spreadsheet and nonspreadsheet models for all areas. The spreadsheet percentage is equal to the number of spreadsheet models in each functional area divided by the total number of spreadsheet and nonspreadsheet models for all areas.

which the traditional OR analyst plays a consulting role to the end user in solving large and complex problems. The popular OR tools for the spreadsheet environment in this group are decision analysis, DSS, linear programming, simulation, and statistics, jointly accounting for 58 percent of all tools used in the spreadsheet environment.

The functional areas of administration and planning, human resource planning, information systems, marketing, quality control, and miscellaneous (Group 2) have intermediate percentage penetration values. This indicates a certain acceptance or maturity in the use of spreadsheet models in these areas compared to Group 1. The most popular tools of Group 1 account for 50 percent of all tools used by Group 2 in the spreadsheet environment. In addition, forecasting and "other tools" represent 13 percent and 26 percent of all tools used by Group 2, presumably indicating the use of a larger diversity of tools.

Accounting and auditing and finance applications have the highest percentage of spreadsheet penetration. These would be considered less traditional OR application areas than those of Group 1 and Group 2. Nevertheless, users in these areas have apparently acquired access to spreadsheets and expertise in using them and are using OR tools in a determined fashion. The distribution of the main OR tools in the spreadsheet environment is: statistics (23 percent), forecasting (18 percent), linear programming (12 percent), simulation (12 percent), decision analysis (eight percent), DSS (eight percent), and project manage-

	Functional Area	Percentage of Spreadsheet Penetration in Each Functional Area
Group 1	Research and Development	33.5
	Manufacturing	35.6
	Facilities and Transportation	37.0
Group 2	Information Systems	48.2
	Administration and Planning	48.6
	Marketing	49.4
	Miscellaneous	52.3
	Human Resource Planning	54.8
	Quality Control	58.2
Group 3	Accounting and Auditing	65.6
	Finance	77.5

Table 3: The functional areas are categorized into three groups based on their percentage of spreadsheet penetration. The functional area labeled "miscellaneous" includes responses checked as defense, education, international business, health care, and other, which were individually too low to display separately. The percentage spreadsheet penetration is equal to the number of spreadsheet models in each functional area divided by the total number of models in that functional area multiplied by 100.

ment (eight percent).

Use of OR Tools in Functional Areas

The data show that certain OR tools exhibit a consistency with regard to the amount of group spreadsheet penetration. For each group, we define the spreadsheet penetration of an OR tool as the percentage of all (spreadsheet and nonspreadsheet) models that use this tool in the spreadsheet environment. Three main subsets of tools emerge: (1) decision analysis and DSS; (2) inventory, linear program-

Subset	OR Tool	Group 1	Group 2	Group 3
1	Decision Analysis Decision Support Systems	50%	61%–72%	50%
2	Inventory Linear Programming Project Management Simulation Statistics	21%–30%	38%–50%	50%–86%
3	Expert Systems Forecasting Heuristics	9%–13%	42%–67%	50%

Table 4: The OR tools are classified into three subsets based on the percentage of all (spreadsheet and nonspreadsheet) models in a group that use the tool in a spreadsheet environment. The values in the table are displayed across the three functional area groups identified in Table 3.

ming, project management, simulation, and statistics, (3) expert systems, forecasting, and heuristics (Table 4).

Two tools, network methods and queuing, do not appear to conform to the characteristics of any of the subsets and are omitted from Table 4. Network methods exhibits poor penetration across all groups (seven percent for Group 1, 25 percent for Group 2, and zero percent for Group 3). We surmise that this is because of the nature of these functional areas that have large and complex problems that cannot readily be implemented in a spreadsheet environment. This also may explain the lack of use of spreadsheet models in the transportation industry. Queuing exhibits a moderate to high penetration for Group 1 (32 percent) and Group 2 (57 percent). For Group 3, however, we have no data, which may stem from the fact that queuing tools are not usually applied in the finance and accounting domains.

The lower spreadsheet penetration of OR tools in Group 1 can be explained by the fact that Group 1 is the traditional OR domain with large and complex problems. Many OR tools are ideal for these problems, and this group made use of special purpose packages long before the advent of spreadsheets. Consequently, the members of this group see spreadsheets as somewhat inappropriate for their requirements despite well-documented benefits. We surmise that this is through a mixture of inertia and prohibitive costs in redesigning existing applications for spreadsheets as well as their perceived lack of performance (for example, small size and low speed). Group 1, however, named decision analysis and DSS as the OR tools with the highest spreadsheet penetration for their applications. This may be because there are fewer widely known and established traditional packages in these areas, and so this niche has been occupied by spreadsheets, being used as aids to decision making.

The moderate to high group penetration values of all OR tools (with the exception of network methods) for Groups 2 and 3 indicate that spreadsheets are indeed instrumental in bringing these tools to end users. Group 2, in particular, has the highest penetration of decision analysis and DSS in their spreadsheet models. This could be partly explained by the inclusion of information systems and miscellaneous areas in this group (miscellaneous areas contain defense and health care), and partly by the fact that spreadsheets are used as decision aids, in the comparative absence of standard solution packages.

Group 3's moderate penetration of all OR tools and high penetration for most of the classic OR tools (inventory, linear programming, project management, simulation, and statistics) appears to support the notion that spreadsheets are instrumental in bringing OR tools to end users. This is evidenced by the fact that Group 3 end users (accountants and financial managers) are not considered users of traditional OR tools, yet they are readily identified as heavy users of spreadsheets.

Integration of Different OR Tools

We analyzed the survey data for spreadsheet applications and for nonspreadsheet applications to see which OR tools are being used in conjunction with other OR tools (Figures 3 and 4). The total level of integration and the relative distribution of

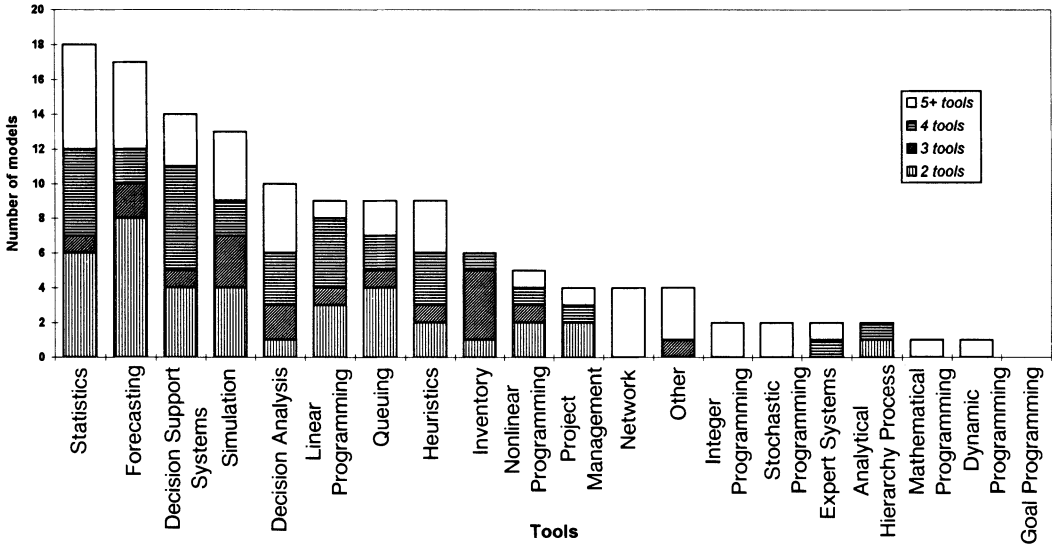

Figure 3: The stacked bars represent the number of spreadsheet models where exactly two OR tools, exactly three OR tools, exactly four OR tools, and finally five or more OR tools were used. The OR tools are sorted in descending order of the total number of spreadsheet models using that tool.

the number of tools used in a model exhibit a similar pattern for the spreadsheet and nonspreadsheet environments. Some tools, such as inventory and expert systems, are somewhat more integrated in the nonspreadsheet environment. The spreadsheet environment itself does not appear to be facilitating integration among tools; the

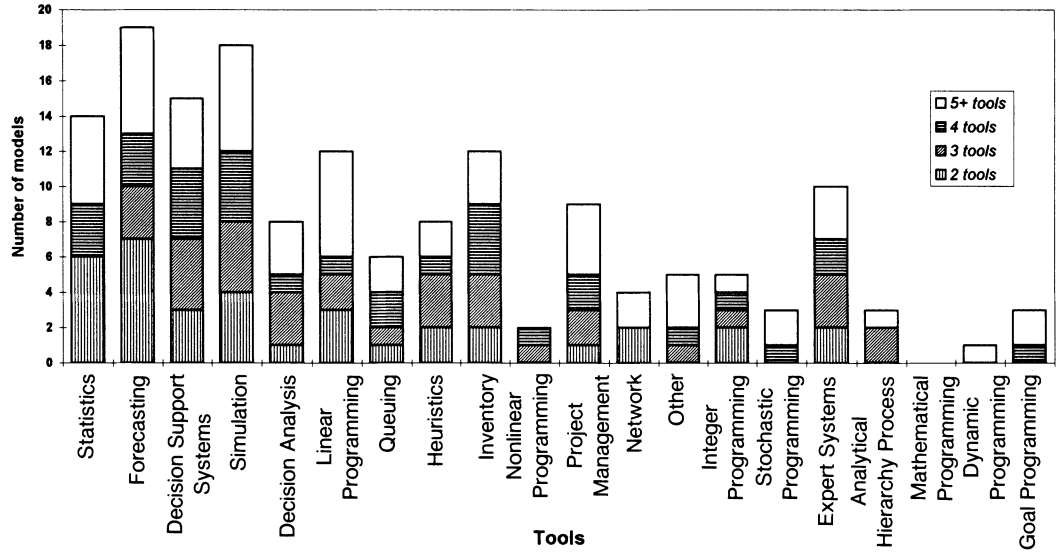

Figure 4: The stacked bars represent the OR tools integrated in nonspreadsheet models. The OR tools are sorted in the same order as in Figure 3 for convenience of comparison.

integration seems to be taking place owing to the inherent nature of the tools themselves.

Perceived Benefits and Limitations of Spreadsheets

Bodily [1986] discussed how spreadsheets can play a significant role in introducing the OR/MS tools to end users. He mentioned some of the virtues of spreadsheets, such as their interactive nature, their ability to support what-if analyses of all kinds, and the built-in presentation facility, that may help to make the spreadsheet medium popular with end users and the OR community. He also pointed out some limitations of spreadsheets that may inhibit implementation of OR tools in the spreadsheet environment, such as the lack of speed of models implemented in the spreadsheet environment, the inability of spreadsheets to support large OR applications, and spreadsheets' inadequate support for complex programming logic.

Group 1	
End-user acceptance	1.82
Speed	2.06
Presentation quality	2.37
Cost	2.38
OR implementation	2.42
Ease of modeling	2.42
Interactiveness	2.64
Group 2	
End-user acceptance	1.49
Ease of modeling	2.10
Speed	2.22
Interactiveness	2.32
Cost	2.36
Presentation quality	2.46
OR implementation	2.86
Group 3	
End-user acceptance	1.67
Speed	2.47
Ease of modeling	2.56
Presentation quality	2.67
Interactiveness	2.87
Cost	2.87
OR implementation	3.00

Table 5: The table presents the results for the three groups of end users identified in Table 3, ranking the important features of their nonspreadsheet applications. Each of the features was ranked on a scale of 1 to 5, 1 representing very important and 5 representing not important at all.

We asked respondents to rank seven key predetermined features (cost, ease of modeling, end-user acceptance, interactiveness, OR implementation, presentation quality, and speed) in order of importance for each of the nonspreadsheet applications they described (Table 5).

End-user acceptance of the applications was the topmost priority for all three groups of users. Speed also appears to be quite important across the groups, whereas interactive capabilities rank quite low in importance for all three groups, contrary to intuitive expectations. This may be partly because some respondents did not interpret "interactive capabilities" as "the ability to support what-if analysis." Group 1 gave some priority to the issue of implementation of OR tools, while the other groups ranked it relatively unimportant. This is not surprising given that Group 1 is made up of users of traditional OR tools with large and established OR applications and hence implementation of OR tools is more important to them than it is to Groups 2 and 3. In comparison, ease of modeling has higher priority for Groups 2 and 3 than for Group 1.

We also asked the respondents to consider possible difficulties in implementing their nonspreadsheet applications in a spreadsheet environment (Table 6). The

	Group 1 Yes / No	Group 2 Yes / No	Group 3 Yes / No
Application is too large for spreadsheet implementation	$\frac{44}{44} = 1.00$	$\frac{43}{48} = 0.89$	$\frac{31}{56} = 0.55$
Spreadsheet implementation will be computationally too slow	$\frac{57}{26} = 2.19$	$\frac{42}{42} = 1.00$	$\frac{38}{50} = 0.76$
The logic of the application will be too complex to model in a spreadsheet	$\frac{79}{20} = 3.95$	$\frac{59}{31} = 1.90$	$\frac{31}{69} = 0.45$
Implementation in a spreadsheet will require too much programming	$\frac{81}{9} = 9.00$	$\frac{67}{22} = 3.05$	$\frac{63}{31} = 2.03$
Linking the spreadsheet model to other systems necessary would be difficult	$\frac{42}{37} = 1.14$	$\frac{33}{43} = 0.77$	$\frac{44}{44} = 1.00$

Table 6: The opinions of end users' rating the perceived limitations of spreadsheets are expressed as ratios of percentages of users responding "yes" and "no" to the issues raised, across the three groups identified in Table 3 (the total of "yes" and "no" responses does not add up to 100 percent because of a "no opinion" category).

possible limitations of a spreadsheet implementation addressed in the survey were (1) the inadequacy of spreadsheets to handle large applications, (2) the lack of computational speed, (3) the limitation of spreadsheets in handling complex logic, (4) the need for excessive macro writing, and (5) the need for the application to be linked with other external modules. Other spreadsheet limitations could be the inability to easily change the dimensions of index sets and the difficulty of documenting nontrivial models, but these were not addressed in the survey. We asked users to show their agreement or disagreement through yes or no answers for these factors for each of their nonspreadsheet applications.

The majority of Group 1 users feel that the main limitations of spreadsheets in their present form are their inability to handle complex applications, their lack of computational speed, and the need for excessive amounts of programming or macro writing. Group 2 agrees with Group 1, though less strongly. Group 3, on the other hand, leans in favor of spreadsheets, and the majority of the respondents in this group disagree with almost all of the limitations of spreadsheets raised in the survey. Overall, the results are consistent with what would be expected from each of the groups, although it is surprising to see that opinions on the ability of spreadsheets to handle the size of the applications and linking requirements are quite similarly distributed across the groups. One would expect Group 1, the group typically running large and complex OR/MS applications, to be more critical on this issue.

Finally we asked the respondents to indicate if they felt that a spreadsheet implementation would have improved some aspects of their nonspreadsheet applications (Table 7). None of the groups think that spreadsheets would have provided a better interactive environment or would have helped in getting better presentation qual-

	Group 1 Yes / No	Group 2 Yes / No	Group 3 Yes / No
Spreadsheet model will provide better interactive capabilities	$\frac{25}{55} = 0.45$	$\frac{23}{56} = 0.41$	$\frac{25}{62} = 0.40$
Spreadsheet will provide better presentation quality of the solution	$\frac{25}{64} = 0.39$	$\frac{30}{57} = 0.53$	$\frac{25}{62} = 0.40$
Spreadsheet will provide the output more easily	$\frac{30}{54} = 0.56$	$\frac{39}{49} = 0.78$	$\frac{50}{44} = 1.14$

Table 7: The opinions of end users' rating the perceived desirable features of spreadsheets are expressed as ratios of percentages of users responding "yes" and "no" to the issues raised, across the three groups of end users identified in Table 3 (the total of "yes" and "no" responses do not add up to 100 percent because of a "no opinion" category).

ity of the solution. Once again, this may be partly due to their not perceiving that interactive capabilities imply the ability to support what-if analysis. The groups differ only about the ease of getting the appropriate output from the applications. Group 3 speaks in favor of spreadsheets, but the ratios are too close to make any strong statement. It is indeed interesting to see that even the group with highest use of spreadsheets does not feel that strongly about the desirable features of spreadsheets. This may stem from the fact that the computing environment in general, especially in PC-based applications, is getting more user friendly, the interfaces are becoming easier to learn and use, and almost all of the applications developed nowadays feature pull-down menus, online help facilities, and easily obtainable outputs. Spreadsheets no longer retain exclusive rights to the interactive environment, to good presentation quality, or to easy ways of obtaining output. Future research in this direction needs to be carried out to further address this issue.

Conclusion

We investigated Bodily's [1986] conjecture that the spreadsheet medium could be used by end users to solve OR/MS problems and to improve decision making. We found that end users are solving OR/MS problems using spreadsheets, especially those who are already spreadsheet experts. OR/MS models developed in spreadsheets can be found across many functional areas of business, though in varying degrees. Some functional areas still prefer traditional methods for implementing OR/MS tools, while other areas, which are well known for using the spreadsheet environment, show more use of spreadsheets in accomplishing such tasks. Overall, there appears to be a growing acceptance of spreadsheets in OR/MS modeling. However, certain large and complex applications still remain outside the reach of spreadsheets.

References

Berry, T. 1989, "The trouble with spreadsheets," *Personal Computing*, Vol. 13, No. 7, pp. 61–63.

Bodily, S. 1986, "Spreadsheet modeling as a stepping stone," *Interfaces*, Vol. 16, No. 5, pp. 34–52.

Bookbinder, J. H.; McAuley, P. T.; and Schulte, J. 1989, "Inventory and transportation planning in the distribution of fine papers," *Jour-*

nal of the Operational Research Society, Vol. 40, No. 2, pp. 155–166.

Cornford, T. and Doukidis, G. I. 1991, "An investigation of the use of computers within operational research," *European Journal of Information Systems,* Vol. 1, No. 2, pp. 131–140.

Eppen, G. D.; Martin, R. K.; and Schrage, L. 1989, "A scenario approach to capacity planning," *Operations Research,* Vol. 37, No. 4, pp. 517–527.

Forgionne, G. A. 1983, "Corporate management science activities," *Interfaces,* Vol. 13, No. 3, pp. 20–23.

Freeman, J. 1993, "Spreadsheet gaming and management skills development," *OR Insight,* Vol. 6, No. 1, pp. 9–13.

Ledbetter, W. and Cox, J. 1977, "Are OR techniques being used," *Industrial Engineering,* Vol. 9, No. 2, pp. 19–21.

Liberatore, M. J. 1988, "A decision support system linking research and development project selection with business strategy," *Project Management Journal,* Vol. 19, No. 5, pp. 14–21.

Mendoza, G. A.; Sprouse, W.; Luppold, W. G.; Araman, P.; and Meimban, R. J. 1991, "An integrated management support and production control system for hardwood forest products," *Computers in Industry,* Vol. 16, No. 4, pp. 343–351.

Miller, T. C. and Liberatore, M. J. 1989, "Production and distribution planning in a process firm," *Production and Inventory Management Journal,* Vol. 30, No. 1, pp. 44–48.

Mustafa, M. A. 1989, "An integrated hierarchical programming approach for industrial planning," *Computers and Engineering,* Vol. 16, No. 4, pp. 525–534.

Oren, S. S. and Smith, S. A. 1992, "Design and management of curtailable electricity service to reduce annual peaks," *Operations Research,* Vol. 40, No. 2, pp. 213–228.

Parlar, M. 1990, "Stochastic decision tree analysis on an electronic spreadsheet," *Computers and Engineering,* Vol. 8, No. 2, pp. 225–234.

Pirlot, M. 1990, "A case study in transportation network optimization using a microcomputer," *European Journal of Operational Research,* Vol. 45, No. 2, 3, pp. 251–259.

Roy, A.; Lasdon, L.; and Plane, D. 1989, "End user optimization with spreadsheet models," *European Journal of Operational Research,* Vol. 39, No. 2, pp. 131–137.

Troutt, M. D.; Tadisina, S. K.; and Clinton, R. J. 1991, "Interactive optimization aspects of electronic spreadsheet models for design and planning," *Journal of the Operational Research Society,* Vol. 42, No. 5, pp. 349–355.

Tyworth, J. E. 1991, "Transportation selection: Computer modeling in a spreadsheet environment," *International Journal of Physical Distribution and Logistics Management,* Vol. 21, No. 7, pp. 28–36.

Vazsonyi, A. 1993, "Where we ought to be going: The potential of spreadsheets," *Interfaces,* Vol. 23, No. 5, pp. 26–39.

Walton, H. P. 1989, "The industrial engineering toolbox (IET)," *Computers and Engineering,* Vol. 17, Nos. 1–4, pp. 575–579.