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Graphics and Managerial Decision Making: Research Based Guidelines

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ABSTRACT: Graphical charts are generally thought to be a superior reporting technique compared to more traditional tabular representations in organizational decision making. The experimental literature, however, demonstrates only partial support for this hypothesis. To identify the characteristics of the situations that have been shown to benefit from the use of graphics, existing studies are reviewed in terms of the type of task used, the format employed, and the user experience. The examination of the literature reveals a set of empirically based—though preliminary—guidelines as to when and how to use business graphics.

1. INTRODUCTION

> . . . business graphics have made presentations more convincing, publications clearer and more readable, and analysis and decision-making faster and more accurate. [7]

These claims are fairly typical of what one finds in periodicals directed toward business practitioners. That audience, it would seem, is convinced of the general utility of graphics technology. Brown [7] forecasts a compound growth rate in the use of business graphics of between 45 percent and 65 percent for the rest of the decade. Another popular source, *Datamation* [32], predicts that business graphics hardware alone will soon be a $6.5 billion industry. Further support for the growing popularity of business graphics is a survey of users in which 96 percent forecasted that business graphics usage would increase at least moderately [41].

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Despite the high level of user interest in graphical presentations, there is no strong empirical evidence showing that, if graphics are used, they instantaneously, or over time, improve the quality of information needed for making a management decision. The experimental results from research studies performed to determine the effectiveness of graphics compared to tables have been contradictory. DeSanctis [18] identifies 29 studies that have compared graphics to tables. Twelve of the 29 studies found tables to be better than graphics, ten found no significant difference between the two modes of presentation, and seven found graphics better than tables. Due to the inconclusive results of empirical studies, Ives [35] concluded that "the failure to demonstrate a clear advantage for graphics suggests that the extravagant claims favoring graphic presentation formats may be considerably overstated."

Deceptive graphics are also a problem. From a sample of Fortune 500 companies, 21 out of 50 companies' annual reports contained at least one incorrectly constructed graph [39]. The most common "errors," as one might expect, were distortions of recent trends. Unfortunately, the impact of such misleading graphs on users' perceptions and subsequent analysis and/or decisions are unknown, and thus, in need of research. At present, the only way for users to guard against being misled is to become aware of the potential abuses of graphs.

A study conducted at the University of Minnesota examined the effects of poorly designed graphics [20]. The study found that the use of graphical charts with inconsistent scaling (for example, differing maximum values on the scales of graphs) in a task which required comparisons among charts yielded poorer decision performance than the use of graphs with consistent scaling. The inferior performance persisted even after the subjects had completed five similar tasks. Such preliminary research indicates that individuals are not able to adequately compensate for distortions of data in graphical charts, at least not within a short period of time. These two illustrations indicate why it is important to provide guidelines (or rules for good practice) to persons seeking to effectively use graphics technology in support of business decision making.

At this time, such a set of guidelines (certainly one which is based upon empirical research) does not exist, yet there has been substantial empirical work performed in this area. Our purpose is to rectify this state of affairs by providing an initial set of guidelines. Beyond the two illustrations just provided, we submit several factors in support for guidelines:

- Many users are developing graphic displays using only intuition and rules of thumb.
- With so many individual study results available, there is the danger that a user could be misled by consulting only one or two sources.
- Most importantly, a set of initial guidelines is needed to provide the basis to intelligently move forward in this area. In other words, researchers should be able to replicate and accept certain graphical practice as fact (the base), and add to our knowledge of good graphic practice predicated upon a concrete set of priorities.

The approach we will take is to review the best available empirical research to identify guidelines that can improve the effectiveness of decision supporting graphics usage in organizations. Three areas will be addressed: (1) decision activities in which graphics use should be encouraged, versus those in which the use of graphics is of questionable value, (2) graphic formats which alleviate or even eliminate risks of misrepresentation and misinterpretation of data, and (3) the level of experience necessary for the effective use of graphics.

Before proceeding, three additional comments are in order. First, the reader may note that certain fairly obvious graphic attributes are not addressed by the following discussion, for example, color. The reason is straightforward: not enough work has been performed to provide the basis for constructing guidelines. Therefore, if an attribute is not covered, it can be assumed that the authors have been unable to find enough support for its inclusion in the guidelines. Since this article represents a first attempt at proposing research-based guidelines, our contentions are limited by the type and the amount of research conducted to date, and the number of application areas examined so far.

Secondly, we want to draw attention to the approach which will be taken in presenting the guidelines. A research group at the University of Minnesota (of which the authors are members) has performed a number of investigations in the role of graphics in *decision making*. Therefore, in each of the three areas for which guidelines are proposed, work with which the authors have been associated is related to the results summarized from the general literature pool.

Thirdly, note that we are explicitly restricting our guidelines to *decision making* applications of graphics. Other important business uses of graphics, such as support of communication and/or persuasion [70], have not yet accumulated a sufficient amount of formal study and, therefore, are not discussed in the paper.

2. BACKGROUND

Although some might argue that the lack of a conclusive and complete body of graphics research makes the suggestion of research-based usage guidelines inappropriate, we contend that such is not the case. Our analysis suggests that not only is there enough material to draw upon, but also that initial patterns of effective use are discernable and important for identifying additional areas of study. Regarding usage guidelines themselves, our underlying assumptions are:

(1) *Guidelines* are necessary for the effective use of graphics.
(2) *Guidelines* must be *empirically validated.*
(3) *Task based behavioral research* best supports the development of empirical guidelines.

2.1 Guidelines

There is a point of view to the effect that guidelines for the use of any information technology, particularly computer generated business graphics, are unnecessary, and instead what is needed is a great deal of flexibility in the technology to address a multitude of user needs. The rationale for such a statement is based upon the notion that users of a technology frequently do not know, *a priori*, exactly what they are going to do in any particular situation and, thus, will do what they think best or will take a trial-and-error approach. A counterargument, and one we support, is that it is the very flexibility of contemporary information technology that creates much of the problem. Illustrating this point with graphics as an example, consider that the potential user can easily access hardware and software, presenting a vast variety of options as to output media, style, form, and color. The net effect, of course, is that it is easy to misuse the technology, given the wide set of options that are available (flexibility). Coupled with the absence of tested guidelines, a situation exists in which inefficient and ineffective use of technology is likely.

One advantage of having guidelines is that they encourage users to analyze the problem which the technology is to address, and their objectives in using the technology (for example, is the goal to provide a summary or allow retention of specific data). Additionally, the presence of guidelines will save design time. Paller [49] has addressed this issue, and argues that flexible graphics software makes it more difficult for an inexperienced end user to decide what is an effective display because of the number of choices available. Guidelines should eliminate unnecessary trial-and-error approaches in the use of graphics technology.

Finally, guidelines are needed to reduce misuses and abuses of graphics. With mainframe or workstation based end-user technology, the generation of graphics is shifting to individuals who are inexperienced in creating graphic output and lack formal training in graphic design, thereby increasing the possibility of a proliferation of hard-to-understand and misleading visuals. Unless some sort of standardization for graphic formats, features, and colors is developed, a chaos of incompatible graphics will result.

2.2 Empirically Validated Guidelines

The approach we advocate is predicated upon empirically validated, research-based guidelines. An opposing view is to argue that the current line of research is unnecessary because we already have an extensive set of non-research based guidelines (for a review see [35]). Clearly, the guidelines developed by graphics artists and statisticians over the years provide invaluable knowledge to the computer graphics field. Yet, there have been problems with non-research based guidelines. To illustrate our point, guidelines of this sort suggest the use of a pie or segmented bar chart for representing the parts of a whole [50, 35]. It took a series of empirical studies to determine that this recommendation had some hidden dangers; it was found that the human eye is poor in judging areas from pie charts and making length estimates from segmented bar charts [11]. The point made by this illustration is that non-research based guidelines need empirical validation before they can be relied upon.

2.3 Task Motivated Behavioral Research on Graphs

We submit that the guidelines must take into account the nature of the task supported. Considerable agreement exists to the effect that the characteristics of the task in which an individual is involved is a prime determinant of decision making performance [48, 55, 23]. Several graphics experiments over the years have provided support for this contention that the effectiveness of an information presentation is highly dependent on, or sensitive to, the task being performed [3]. The implication of the focus on task is that: (1) the results of any graphics study can be interpreted solely as a function of the task, and, (2) any comparison or, (3) extrapolation of results in one task activity with those in another is inappropriate unless the researcher also considers the characteristics of each task. Accordingly, given the need to consider the efficacy of graphic formats in a variety of task environments, the long-term goal of this line of research can only be a matrix of *task environments* by *presentation formats*, with a set of contingencies based on *user characteristics.*

Considering the formidable number of tasks in organizational decision making, such a matrix can be argued to be an unreachable objective. On the contrary, it is the authors' contention that the completion of the matrix, per se, should not be a concern to researchers or users. The concern should be on how much more we learn about graphics use as we evolve toward the completion of such a matrix. One of the main benefits of the matrix, at any stage of completion, is that it facilitates the classification of a seemingly infinite number of tasks into a finite number. Moreover, the state matrix helps to determine what is currently known and not known, and thus, what is in need of empirical study (for the researcher), and what should be addressed by trial and error (by the user).

To illustrate this point (for the case of the graphics researcher), we can draw upon one of the results which will be discussed in detail later in this paper. To facilitate our analysis, we will create two task classifications, each addressing a different level of mental activity (elementary information processing and higher order processing). Once the existing studies on the graphs versus tables controversy are mapped to the task classification schemes, it becomes clear that researchers have not taken the challenge of graphics proponents' and vendors' claims as their prime objective. In this instance, we will show that there are numerous published statements about graphs' superior ability to show trends, but that only one study exists that can be used to support all these statements. In contrast, we note that virtually no claims are made that graphs are more accurate in point reading than tables; nevertheless, six such research experiments have been performed to study this phenomenon. Thus, our proposed state matrix immediately lets us learn something about what has been studied about graphics use, and what is considered important to know. In this case we note a severe mismatch.

Beyond helping to identify the high payoff areas for further research, task based research also maximizes the benefits from the experimental methodology. Task based research implies that a researcher defines the phenomenon under study in terms of some task categories. The researcher is immediately forced to think of a problem as a general problem and define the boundaries of the problem in terms of the task categories. For any single study then, it is highly likely that a researcher will select a generalizable example from one or more task categories, not a highly specialized task. Hence, a researcher is unlikely to fall into the trap of studying the phenomenon under highly specific conditions and facing a dilemma of how one specific condition relates to another specific condition. The cost of doing an experiment under the task based approach is relatively low compared to the potential benefits of generalizing over many specific applications.

Finally, for the graphics user, the existence of a matrix simplifies the choice of presentation options when graphics are being considered. In short, development of guidelines, their empirical validation, and their presentation in a task-based format is valuable to both the potential user of business graphics technology and to the researcher seeking to add to what is known.

3. AN ANALYSIS OF GRAPHICS RESEARCH

Consulting the existing literature is a first step in developing a "base" set of guidelines on which practice and further research can build. One way to analyze this body of literature is to explore business graphics research via a framework such as one proposed by Mason and Mitroff [46], which recognizes the importance of presentation format in decision making. Three of the five elements in the framework are relevant for analyzing graphic studies: (1) the type of task or decision activity performed, (2) the type of presentation format employed, and (3) the user characteristics.[1] The two other elements for this framework—organizational context and method of analysis—are not applicable because graphic studies have generally involved controlled laboratory experiments, and have investigated only the final decision outcomes, not the methods of arriving at decisions.

In reviewing the business graphics literature on task, format, and user characteristics, an attempt is made to identify those research conclusions that can be relied upon (in the sense of valid procedures and multiple occurrences of similar results). The "arithmetic summation" method of reviewing is used where several studies exist with reliable research procedures.[2]

3.1 Use of Graphics in Supporting Tasks

Our classification scheme for the analysis of business graphics research separates tasks into two main categories: (1) elementary tasks that involve basic perceptual cognitive information processes (for instance, retrieval of a data value or comparison of two data values) and, (2) decision activities that involve formal higher mental processes such as judgment, integration of information, and/or inference (for example, forecasting). This scheme follows the tradition of decision science [48, 62] in analyzing tasks by the level of mental processing required to complete the task. Within the two categories, we merely utilize the tasks for which sources in the popular literature have advodated the use of graphics. We then map existing studies onto these task categories.

3.1.1 *Use of Graphics vs. Tables in Tasks Involving Elementary Processes.* Vendors and graphic proponents have generally advocated the use of graphics over tables for the following elementary tasks: (1) summarizing data, (2) showing trends and relationships over time, (3) comparing data points and relationships of variables, and (4) detecting deviations or differences in data. We are unaware of any claims having been made, however, to suggest that graphics are more effective for (5) point reading, for instance, extracting values from reports or displays. The rationale most often given in support of using graphics for summarizing data is that graphics provide data in a more concise format and, therefore, data from graphs can be interpreted and understood quickly. For similar reasons, graphics have been advocated as more effective than tables for portraying time series data, and for allowing comparisons to be made more easily. Finally, the arguments given for using graphics to detect deviations is that viewers can see trends and relationships in a glance, avoiding the steps of reading, comparing, and interpreting that are necessary to spot deviations using tabular data.

3.1.2 *Prior research on elementary tasks.* Some empirical results are available to verify the correctness of claims in regard to the use of graphics in elementary tasks. As Table I shows, research only partially supports these claims. No uniform evidence exists that graphics summarize the data more effectively than tables in terms of time spent on the task (point 1). In the seven studies listed in Table I, four found that users of graphs performed faster than those using tables. With respect to the ability of graphs and tables to portray trends, the only study reported in the literature was favorable for graphs. The claimed ability of graphics to show relationships between variables (point 3) has attracted a little more research interest. Three of four studies found graphics superior for depicting relationships between variables. The fourth study supported the use of graphics only when knowledge about the shape of the graph's curve was essential for successful performance. With respect to reading specific values (point 5), five studies have been conducted which consistently encourage the use of tables.

3.1.3 *Research conducted at Minnesota on elementary tasks.* The studies at Minnesota (see Table II) have investigated the usefulness of graphics in summarizing data, depicting trends, and comparing data points and

[1] An analysis of the literature which considers the interaction effects of the three factors on the effectiveness of graphs would be preferable. Unfortunately, such an approach is infeasible because studies on which the analysis is based have not taken such interactions into account.

[2] Quantitative meta-analysis methods are not possible due to the insufficient documentation of the published studies.

TABLE I. Research on Elementary Tasks: Graphs vs. Tables

Tasks	Graphics advocated by	Researched by	Results of research
1. Summarizing data	[6, 47, 61]	[8, 60, 71, 66]	graphs led to faster performance
	[64, 75]	[69, 16]	no difference
		[29]	tables performed better
2. Showing trends	[67, 58, 47]	[72]	graphs led to better performance.
	[6, 52, 64, 26]		
3. Comparing points and patterns	[56, 52, 26]	[72, 9, 24]	graphs led to better performance.
	[30]	[8]	graphs useful for interpolation.
4. Showing deviations	[64]	none	
5. Point/value reading	none	[72, 8, 44, 3]	tables led to better performance.
		[24]	graphs were better.
		[73]	no difference.

patterns of variables. Table II briefly illustrates the tasks, subjects, and the results obtained.[3] From our work to date on elementary tasks, there is evidence that graphs yield faster comprehension of data, and partially improve performance in tasks involving the detection and comparisons of trends.

3.1.4 *Use of Graphics vs. Tables in Supporting Higher Level Decision Activities.* In addition to tasks involving elementary processes, graphics proponents have identified decision tasks involving higher level mental processes in which graphics are claimed to improve decision productivity. These activities are: (1) problem finding, (2) comprehension of information, (3) performance review, (4) forecasting, (5) exception reporting, (6) planning or allocation of resources, and (7) exploratory data analysis. In particular, forecasting and planning are two very popular areas for which graphics are promoted and often used in organizations.

may have put excessive emphasis on reading and isolating individual numbers rather than understanding the relationships and trends of different variables.

As with the planning and resource allocation related tasks, research studies have not found strong support for graphs' ability to enhance data comprehension. Only in three out of six studies on information comprehension did graphics users demonstrate a better understanding of information. Even less can be said about the usefulness of graphics in problem finding, performance review and monitoring, forecasting, and exception reporting because these areas are almost totally lacking in any empirical investigation.

3.1.6 *Research conducted at Minnesota on higher level decision activities* To better understand the issue of what decision supporting applications are appropriate for graphics usage, researchers at the University of Minnesota have investigated the effectiveness of graphics in (1) problem finding, (2) forecasting, and (3) information comprehension (See Table IV). Our research in the context of problem finding was performed for two reasons. First, this area was totally "untouched" by prior graphics research. Second, problem finding was considered likely to benefit from graphics because successful problem identification relies upon spotting trends of current performance, and comparing these to historical patterns. Consistent with the earlier finding that graphics are superior in trend analysis, a forecasting task was chosen as a second application area. A third domain, information comprehension, was studied in two contexts: (1) financial statement analysis and (2) managerial reporting. The use of graphics in these two areas was examined because of the rapid increase in the use of graphical forms of presentation in corporate financial statements and other reports. Table IV presents the results from our studies as well as the subjects and research designs used.

TABLE II. Research at Minnesota on Elementary Tasks: Graphs vs. Tables

Tasks	Subjects	Results of research
1. Summarizing data (1)	51 grad students	graphs led to faster performance than tables (F prob = .017).
2. Showing trends over time (1)	51 grad students	graphs led to better performance than tables (F prob = .006).
[37]	46 grad students	no difference between graphs and tables.
3. Comparing points and patterns	51 grad students	tables were better in comparing points (F prob = .001); graphs were better in comparing patterns (F prob = .070).
[37]	46 grad students	no difference between graphs and tables.

(1) The methodology was the same as reported in [38].

3.1.5 *Prior research on graphics vs. tables in supporting higher level decision activities* As with elementary tasks, some research results can be used to verify the claims for the use of graphics to support higher level decision activities. Table III lists the application categories, the proponents who have advocated the use of graphics in those areas, and the results of the related research. These results have provided very little evidence that decision maker productivity can be increased by the use of graphical decision aids. For example, the findings on the value of graphics in planning and resource allocation related tasks are consistent but in total disagreement with the claims of graphics' advocates. None of the studies found graphics to perform better, and in some instances, graphics even led to poorer decisions. Since successful performance in planning oriented tasks relies a great deal on identifying key trends, these results are somewhat surprising, particularly in the view of research that has found graphs to perform well in tasks requiring trend spotting (See Tables I and II). These outcomes could be partially due to the context in which the experiments took place; all of the studies used business games. This type of task environment

As Table IV shows, the Minnesota studies failed to support the position that graphs have a positive impact on problem finding or information comprehension in the financial analysis context; however, graphics were found to be a superior reporting method in a forecasting application and in a reporting situation in which a great amount of information was presented at one time.

Overall, the research results reported do not provide

[3] The experimental material for the studies conducted at the University of Minnesota can be obtained from the first author.

TABLE III. Research on Decision Activities: Graphs vs. Tables

Tasks	Graphics advocated by	Researched by	Results of research
1. Problem finding	[60, 65]	none	
2. Information comprehension	[45]	[68, 43]	no difference between tables and graphs.
		[74, 42]	graphs were found to be more effective
		[66]	no difference in accuracy; faster interpretation with graphs.
		[51]	tables led to better comprehension.
3. Performance review	[53, 36] [64, 27]	[25]	in situations of great variance, some difference existed between two formats.
4. Forecasting	[56, 64]	[42]	no difference between tables and graphs.
5. Exception reporting	[6, 36] [64]	none	
6. Planning or allocation of resources	[60, 40] [64]	[5]	graphs led to better performance.
		[43, 16, 1]	no difference between tables and graphs.
		[29, 54]	tables led to better performance.
		[2]	tables led to better decision making; graphs led to faster decisions.
		[3]	graphs were found to be useful.
7. Exploratory data analysis	[75, 10]	none	

any overwhelming evidence that would encourage the use of graphics in the referenced application areas. However, since there is no overall decrease in effectiveness when graphics are used, there is no reason to constrain the use in these areas of application because of concerns about *impaired* decision making (as long as the proper graph formats are employed). In short, in what we refer to as higher level decision applications graphs and tables appear to be about equal in overall performance.

3.2 Proper Graphic Formats to Use

The research on graphic formats is examined according to the same classification scheme we used to analyze graphs *vis-a-vis* tables in elementary tasks. Table V presents the prior research on graph formats mapped into this scheme. Table VI adds the results generated by the Minnesota group according to the same task categories. Note that the research reviewed is concerned only with the differences between the formats of presentation (for instance, tabular versus graphical presentation). Color is not considered because: (1) it is not a graphical feature; color can be added both to tabular and graphic presentations,[4] and (2) few studies have yet been performed in the application of color in an organizational context.

3.2.1 *Summarizing data.* Bar and line formats appear to be the most appropriate for summarizing data, because both formats emphasize the central tendencies of a pool of data. Our study comparing line and bar charts indicates that users of line charts are able to view data, and make decisions faster, than the bar chart users, although the users of the latter find the bars to be more understandable and readable (Table VI). An additional study shows that the placement of multiple variables versus one variable in each graph further increases the speed of comprehension (Table VI). Thus, on the basis of available research results, grouped line graphs are indicated as preferred for summarizing data, but users may be more comfortable working with grouped bar charts (see examples in Figure 1).

[4] Research on color graphics has found color to have certain effects beyond the format used [4].

TABLE IV. Research at Minnesota on Decision Activities: Graphs vs. Tables

Tasks	Subjects	Results of research
1. Problem finding [37]	46 grad students	no difference between tables and graphs on performance; except tables were found more readable (F prob = .061).
2. Information comprehension [19]	154 undergrad students	no difference of performance; tables were found less difficult to read (F prob = .023).
[21]	363 undergrad students	graphs led to better performance when only simple impressions were to be made (F prob = .07).
3. Forecasting [19]	320 undergrad students	graph users performed better and found the task less difficult (F prob = .001).

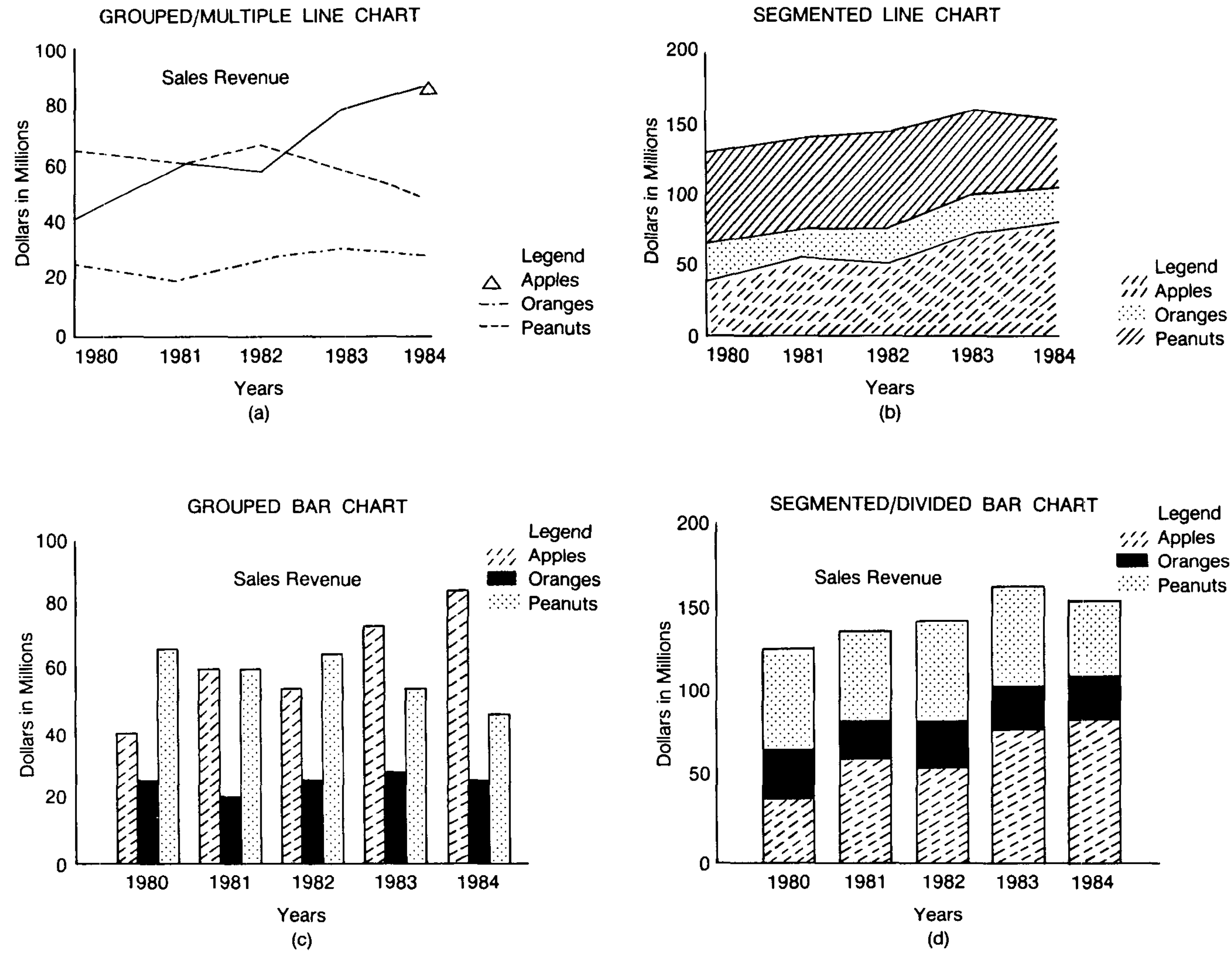

FIGURE 1. Grouped Bar and Line Graphs

3.2.2 *Showing trends over time.* Schmid and Schmid [57] suggest that a line chart is particularly effective in portraying time series data and, according to the trade publications, line charts are the dominant technique for depicting variables over time. However, the research results have not been conclusive when line charts have been compared to bar charts. Our study (see Table VI) and one by Culbertson and Powers [15] have not found any difference in interpretation accuracy between line and bar charts for analyzing trends. With regard to the type of line to use, a study by Schutz [59] suggests the use of multiple-line graphs instead of single-line graphs.

3.2.3 *Comparing points and patterns of variables.* Research examining the representation of relationships between variables has involved tasks comparing either (1) proportions of a whole, (2) patterns of variables, or (3) absolute values. Studies investigating the representation of the component parts of the whole have produced quite inconsistent results with respect to whether grouped bars, segmented bars, or pie charts are the preferred format (see examples in Figure 1). The most recently conducted studies have, however, provided rather conclusive evidence that grouped bars minimize the perceptual problems associated with pie and segmented bar charts [11]. Cleveland and McGill have found the human eye to be more accurate in reading grouped bars that have a fixed common baseline than making length estimates of the segments from divided bar charts or judging areas from pie charts. Consistent with these perceptual results is the finding that in tasks requiring comparisons of patterns of variables, grouped line and grouped bar charts are easier to use than segmented line or bar charts. In addition, people tend to overestimate the length of a vertical bar, thereby suggesting the use of horizontal bars in examining relationships between variables [31]. Finally, when a task requires only a comparison between abso-

TABLE V. Research on Graphical Formats

Tasks	Researched by	Results of research
1. Summarizing data	none	
2. Showing trends over time	[72]	line graphs performed best for dynamic comparisons.
	[15]	bar charts were easier to read than line charts.
	[58]	line graphs were better for time series data than horizontal and vertical bar charts.
	[59]	multiple lines per graph were superior to multiple single line graphs.
3. Comparing points and patterns	[22]	circle graphs were read as accurately as divided bars.
	[72]	for complex static comparisons, bar graphs were best.
	[14]	with fewer than five proportions, a pie chart was better than a bar chart.
	[13]	bar charts were found to lead to more accurate performance than circle charts.
	[31]	people overestimated the length of the vertical bar.
	[15]	grouped line graphs were more readable than segmented line graphs.
	[11]	in general, position statements were more accurate than length and angle judgments.

lute data points, our results indicate that single-variable bar charts facilitate more effective comparison than multiple-variable bar charts (Table VI).

3.2.4 *Point reading.* Research studies reviewed in the previous section clearly communicated that no benefits result from using graphical reports instead of tables for the purpose of extracting single values and, what is more important, graphical charts may even lead to poorer performance. However, if graphs are used for such a task, the following research results should be known: (1) determining points from a line graph is much more difficult than from bars because line graphs do not clearly pinpoint the exact y-value for a given x-value [15], (2) readers tend to completely overlook any figures on scales [67], (3) data values at the end of the bars increase the accuracy of decisions [20], and (4) placement of values on the bars is more effective than grid lines [15, 63].

The above discussion addresses only a small portion of available graphical formats and their uses. Nonetheless, they provide information on what the preferred graphical formats are (for example, grouped bar charts). Additionally, they help avoid the "poorer" formats (for instance, pie charts, segmented line and bar graphs).

3.3 The Characteristics of an Effective Graph User

User experience is only one of the individual difference factors studied by graphics researchers; yet, it is the most important. Evidence indicates that the decision maker who lacks graphics experience is likely to get little value out of a graphical display, even when the use of graphics is suggested by the task at hand and the proper format and features are selected. In contrast, cognitive style—although more frequently studied than user experience [43, 42, 29, 17, 1, 28]—does not appear to have any strong relationship with the information presentation format. Moreover, some researchers [34] have labeled cognitive style research as weak and inconclusive, and thus, an unsatisfactory basis for deriving operational guidelines.

3.3.1 *Prior Research Concerning the Role of Experience with Graphs.* Researchers who have generally found graphs to be ineffective in aiding decision making have postulated that a user who is unfamiliar with a graphical format must go through a learning process before graphical information becomes meaningful [43, 44, 51, 73]. One persuasive argument is that graphical interpretation is a skill which must be learned before any benefits from graphics can be obtained [18]. The studies

TABLE VI. Research at Minnesota on Graphic Formats

Tasks	Subjects	Results of research
1. Summarizing data	63 grad students	grouped bars led to faster performance than single bars (F prob = .001).
(1)	32 undergrad students	multiple line charts resulted in faster performance (F prob = .032); the overall user satisfaction was higher with bar charts (F prob = .020).
2. Showing trends over time	63 grad students	no difference between single vs. grouped bar charts.
(1)	32 undergrad students	no difference between multiple and grouped bar charts.
3. Comparing points and patterns	63 grad students	single bars were more accurate for comparing points (F prob = .002); no difference in patterns.
(1)	32 undergrad students	no difference between multiple line and grouped bar charts.

(1) The methodology was the same as reported in [38].

by Vernon [67] and Ghani [29] support this contention. Vernon concluded that people must be experienced with graphics, especially in tasks that require the reader to perceive relationships among complex sets of data. Ghani [29], in addition to confirming the findings of Vernon, reported that decision makers perform best with an information format they are familiar with because they have developed heuristics, or rules, for interpreting data from the format. Ghani's finding suggests that any novel format, such as graphs, would likely be at a disadvantage compared to traditional tabular formats, because people lack skills in extracting data and relationships of data, and applying the extracted data.

3.3.2 *Minnesota Research Concerning the Role of Experience.* People's lack of experience with graphics raises two questions: (1) whether individuals can adjust to graphs and (2) how long the adjustment process takes. The Minnesota graphics project has begun trying to answer these questions. DeSanctis and Jarvenpaa [20] found evidence that there is, in fact, a learning curve associated with the use of graphs. In the study, practice in using graphic reports to make financial forecasts led to improvements in decision quality. No similar practice effect was found with tables. The study supported the notion that people can adjust to graphs over time, and such adjustment is required for the effective use of graphs. The length of the study was, however, too short to establish the time required to develop fully the skills of interpretation for graphs.

The results obtained by the Minnesota research group suggest that future graphics research, to be valid, should either carefully control for learning effects or should include this factor as an independent variable. The results of any study not meeting these conditions must be viewed with skepticism.

TABLE VII.

Use Graphs for:
- Quick summary of data.
- Detecting trends over time.
- Comparing points and patterns of different variables.
- Forecasting activities.
- Information reporting when a vast amount of information is presented and relatively simple impressions are to be drawn.

Use Tables for:
- Reading of individual data values.

Use:
- Line or bar charts for summarizing data; line graphs are preferred over bars if the speed of comprehension is important.
- Grouped line or bar charts for showing trends over time.
- Grouped bar charts for presenting parts of a whole; do not use pie or segmented bar charts.
- Grouped line or bar charts for comparing patterns of variables; do not use segmented line or bar charts.
- Horizontal rather than vertical bars for making comparisons between variables.
- Single line or bar charts for comparing individual data points between variables.
- Data values on the top of the bars for point reading.

The Users Should be Cautioned About:
- The existence and durability of the "conditioning bond" toward tables.
- The use of graphs in a single presentation to people not familiar with them.
- The need for sufficient practice to allow for the adjustment to the graphical presentation format.
- The necessity of an adjustment before any benefits from the usage of graphs can be obtained.

4. CONCLUSION

The purpose in conducting this analysis is to increase the awareness among managers, designers, users, and researchers of the advantages and disadvantages of graphical presentation in support of organizational decision making. Our recommendations, as well as cautions, are highlighted in the form of *tentative guidelines* which are summarized in Table VII.

For users of business graphics in decision making applications, our message is straightforward—use the framework we present to think about the nature of an application, and, where appropriate, follow the guidelines that have been presented. In addition, support researchers in their work to verify these guidelines and to expand them.

For persons wishing to conduct research in the use of graphics in support of organizational decision making, we have a more expansive set of admonitions. We strongly urge researchers who want to contribute to the current line of work to both verify and expand this first set of proposed guidelines. After engaging in graphics research for several years, the authors continue to believe that well-designed studies that: (1) examine the stable components of using graphics, (2) adopt a task focus, and (3) involve laboratory experimentation can result in robust empirical guidelines.

Future research should particularly continue to study the importance and validity of the guidelines proposed in graphic design books, especially the ones dealing with the stable components of using graphics (such as scaling). Areas that are subject to constant changes in technology—for example, graphic output and input technology—should have the lowest research priority. This is because of the long lead time required for an experimental investigation to be conducted in these areas. The current findings on user experience also suggest that studies should be conducted over a long enough period of time to account for the user experience factor, and involve multivariate designs which consider the simultaneous effects of the task, format, and user experience.

Future researchers are further encouraged to explore task classifications with theoretical support. If the effects of graphs are as dependent on the task as the current research suggests, any theoretical support for the guidelines will be contingent on the theory of tasks. An important step in developing a theory of tasks is the development of a taxonomy of tasks, or a taxonomy of task characteristics [33].

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L'Ecuyer *(continued from p. 749)*

TABLE V. Results of the "Second Trial" Tests

Generator	Test no.	Previous δ	New δ
Combined 16-bit	18.	.0252	.4139
32-bit MLCG	3.	.0071	.1098
32-bit MLCG	6.	.0479	.1967
32-bit MLCG	13.	.0255	.0228

with $m = 2147483399$ and $a = 40692$. Box (c) is the output from the proposed 32-bit combined generator: No lattice structure is apparent. These graphics are just more empirical evidence supporting the combination.

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