AN ANALYSIS OF APPROACHES IN MAP DESIGN

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Although I missed the Monday afternoon session, due to my witnessing of a serious automobile accident near the Dulles Air Terminal, I was fortunate in being able to read George McCleary's comprehensive notes taken during that session. What I hope to discuss today is, first, the general area of the background and history of map and chart design investigations prior to the fifties and then, some few words on the relationship of the psychological approach to map design. Then I plan to follow with a discussion on the modern focus on information management systems which use map information. In addition, I prepared for the purposes of this meeting, some visual aids as a sort of "strawman" to explain what might be termed the psychological research and design problem in relation to subsystems which are parts of larger information management systems. I think that this ties in with things that Arthur Robinson said this morning and several speakers said yesterday.

I first encountered this whole realm back in the late forties and early fifties. After I finished my academic training, I immediately went to the Aeronautical Chart and Information Center in St. Louis, and pretty soon got involved in map and chart design. The first thing I tried was literature research and I looked around to see what kind of information there was in the cartographic literature to learn how to improve the design of maps and aeronautical charts. Ultimately, I got back to such noteworthy authors as Max Eckert, Karl Peucker, and others, much of which was in German and had not been translated into English, so that a bit of translating was necessary to find out what they were talking about. In the 1940-50 period, of course, was Arthur Robinson and his noteworthy Look of Maps, but unfortunately, it didn't deal directly with the design of aeronautical charts.

Additional research led quite readily to what was then called "human factors" and "human engineering" research, in which people were concerned with man-machine interaction, display problems and the design of displays for use by pilots, in the control of aircraft for orientation and navigation purposes. In this late forties and early fifties time period, you might remember that jet aircraft were coming into wide use and the speed and complexity of the aircraft was increasing. The human being's capabilities as part of this man-machine system were being overburdened by being forced to use displays and equipment that had been designed prior to World War II.

The literature available was generally related to display design through either a physics, physiological, or psychological approach. In almost all cases, I found that there was considerable misunderstanding by cartographers as to how laws of the physics of light applied to map design, especially if the human factors and human engineering concepts were followed. I believe that even today there is little evidence of a connection between the laws of physics and what people learn when they read a display. Obviously, they see color, but learning or making "course of action" decisions requires more than a response to specific wavelengths. For example, when going back to the work done in Germany and Switzerland and elsewhere, I found out that some of those noteworthy authors believed that short wavelengths were obviously useful in showing lower elevations because all human beings associate short wave lengths (blues and greens) with lower elevations, while higher elevations are associated with the longer wave lengths toward the red end of the visible spectrum.

In looking into the physiological and psychological research — there was a lot of it -- I found again that what was reputed to be psychological was somewhere on the borderline between what psychologists call psycho-physiological and psycho-physical -- I was not sure at the time of the difference. Such physiological factors as advancing and receding colors had been used by cartographers as map design parameters. It became obvious later, that although there is a physiological relationship of the eyes accommodating to warm and cool colors, in-so-far as advancing and receding space is concerned, once the colors become part of a display such as a map or instrument, the eye-brain combination no longer perceives a focal length difference.

Then, in the case of some of the so-called psychological parameters, there is such a thing in cartographic literature called atmospheric perspective, such as the haze when we look at some distant mountain. Whether or not there is a carry-over of clues for distance that the eye sees and a map design parameter is unproven. This, of course, is seen in the literature in relation to the use of greyish, hazy color for lower elevations (farther from the eyes of the map reader) and the bright, sunny colors to show higher elevations (closer to the eyes of map users). People also talked about a pleasing appearance as a necessity in map design -- somehow or another a pleasing appearance was supposed to imbue a user with some kind of confidence. It didn't take too long to find that some of this type research was inappropriate in terms of a human factors approach. Also, the work of John Sherman and Willis Heath and others in making maps for the blind indicated that if the logic that maps had to be pleasing in appearance for sighted individuals to gain confidence was valid, then obviously they should feel pleasant to the fingertips of blind individuals. That didn't exactly make sense. What John Sherman said this morning about most of the design and information systems parameters being directly applicable whether a person is sightless or sighted, I think makes a lot of sense. My research has indicated this also.

People such as James Gibson, George Hoover, Alphonse Chapanis and others were instrumental in a lot of the psychological research in the 1940-50 time period that dealt with products, devices, and graphic displays for use in specific use situations. It is necessary to emphasize the specific use situations, since that's where the user gets needed information from the map or graphic display. Gibson, in approaching what he called the psycholphysics of problems in visual perception, developed a case for something called the "visual world" and the "visual field." The visual world, as he defined it, is a stable world that we see when we move our head and move our eyes -- everything stays in place -- even if we stand on our head the world is still there and doesn't fall apart. This is what he called the world of everyday experience: the world we live in -- it has color, it has motion, it has all these things, but it remains stable and up-right.

Then there is something that he calls the visual field -- something that you see if you hold your head still and you introspect about what your eyes are seeing at any one moment of time. We all navigate the same in the visual world, since if there is a chair in our way when we walk across the room, we miss it because we are reacting to a perception of the visual world. We don't really introspect on the chair being there, in order to walk around the chair. However, Gibson points out that if you are going to design something, make something for someone to approximate the clues that you get in the visual world, you've got to understand the kind of clues that you would expect to see if you were in this boundless, stable visual world. In the visual world we know that railroad tracks do not come together, but if we paint a picture of railroad tracks, in the visual field they do come together. We know that one clue for distance in the visual field is that distant mountains appear hazy. If you paint a picture, you paint them to appear as they appear in the visual world. However, that same rule doesn't apply to the appearance of anything other than distant objects or mountains that you are trying to give someone a clue that they are a considerable distance from the viewer. There are many other clues in between the viewer and the mountains that also tell him the mountains are far away. Perspective itself, e.g., converging railroad tracks and size of objects tell him the mountains are far away. On the map, use of that same atmospheric perspective where there are no other clues for distance, does not provide the human in the visual world with information (or clues) that the lower elevations are further away from the eye than higher elevations. From Gibson's standpoint, that kind of design logic is very questionable.

Another interesting point in relation to daily functioning in the visual world and graphic design problems is that, unless a psychophysical approach to human factors analysis is followed, the designers (cartographers in this case) make their own approximations of logic. Or, as someone said this morning, they appear to use intuition if they have not been trained in a particular field such as psychology or graphic design. But, there is even a serious problem in knowing precisely what psychological concepts have been found valid in graphic design. Gibson attempted to develop a "Proposal for a Theory of Pictorial Perception," but his work never got beyond the proposal stage.

There is an excellent lesson which can be learned from the pre-World War II U. S. Army Air Corps' visual testing of depth perception by potential pilots being asked to line up two sticks, ten or twenty feet away. This was to test depth perception which was assumed to be a valuable clue for landing an airplane. During World War II, psychologists such as Gibson said that since depth perception is only one clue for distance, and it is only good in humans up to fifty or a hundred feet in front of the eyes, why use this test? He also pointed out that so many other clues are available, such as convergence, rate of speed objects move past, size of objects, etc., that one-eyed pilots experience little difficulty in landing an aircraft. There was what appeared to be a well-founded concept, which was proven unsound by "visual world" research. I believe many of our cartographic conventions would suffer the same fate, if examined with a similar approach. At this meeting there have been references to use of warm and cool colors for such things as maximum and minimum temperatures. These same individuals used warm colors for incidence of thunderstorms and hence, their logic escapes me.

During and after World War II there was much research into the design of cockpit instrument displays used for monitoring and guiding the functioning of aircraft systems. The cockpit design at the time people started to train on pre-World War II aircraft instruments followed little logic. Pilots were told they had to construct a picture of the airplane and its attitude by reading about thirty or forty different dials, and in their brain, concoct the present attitude of the aircraft (See Figure 1). Now it wasn't long after that the people got busy, i.e., the human factors people, and they said "look, that doesn't make sense." We're not unburdening the visual task of the pilot — we're making his job more difficult. So they fed this information into, what I call here, an integrator or a small computer system — and out of the computer system comes an integrated picture, if you will, of the present attitude of this aircraft in relation to the earth's surface. (See Figure 2). This little aircraft on this display was simply an intergration of what the instruments would have told the pilot and the pilot could

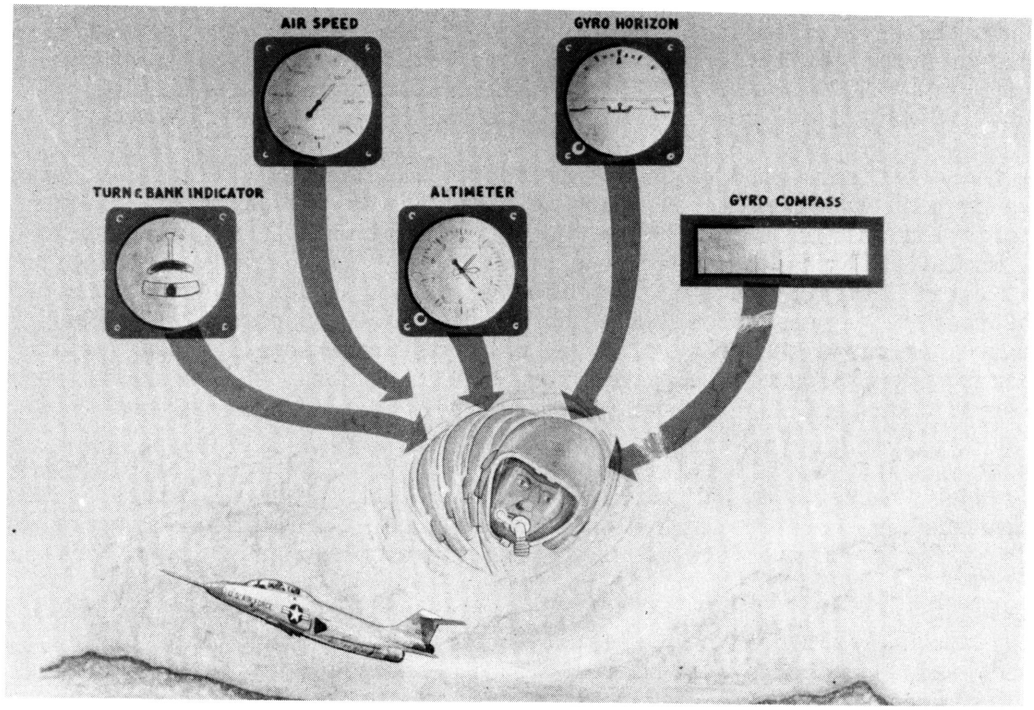

Figure 1

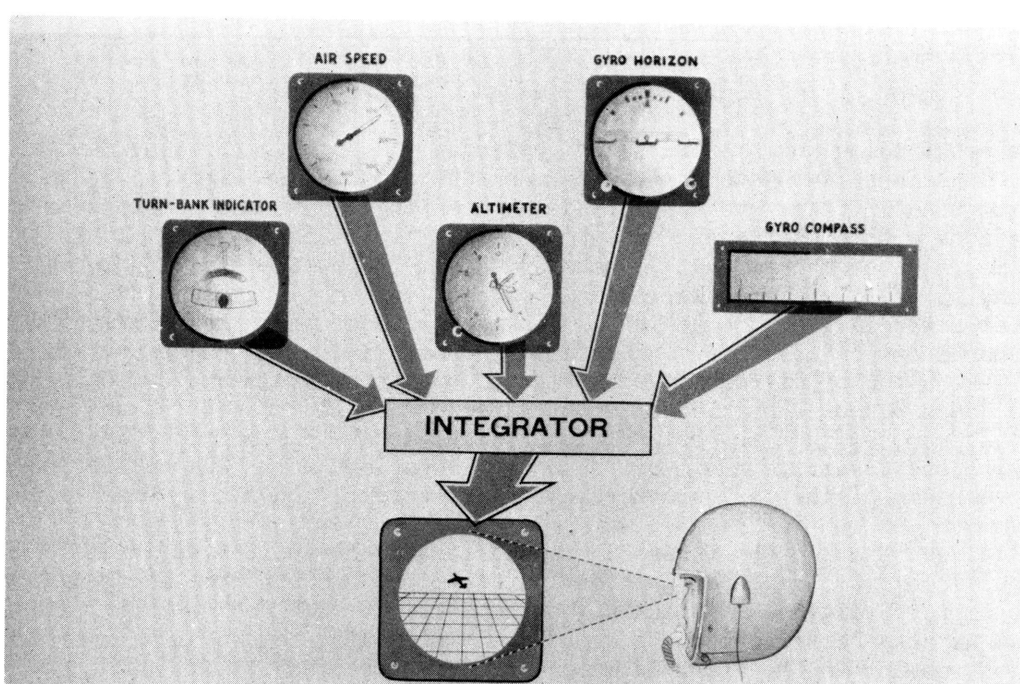

Figure 2

take immediate action to correct the attitude of the aircraft. It made things so easy that training was made easier and it took less time to train pilots. It made the task of actually flying the faster, more complex aircraft easier than those aircraft flown in World War II. Since I flew from carriers in World War II and I know that it was no easy task, I can appreciate the improved displays.

I think the same kind of logic applies to map design. Figure 3 shows this when we present an aeronautical chart to a pilot. In the light of different kinds of information the pilot requires, he must somehow mentally integrate map information into a whole. All that I am saying here is that it is possible to have what I call an integrated design (Figure 4) in which the map is so designed that the pilot gets the information he needs as quickly and unequivocally as possible, without having to compare various sizes of type, etc., which is traditionally used by cartographers to indicate population of a city and things of that sort. So, again by thinking of an integrated design, we are leading to improved design parameters.

Lastly, I am going to be talking about closed loop, man-machine systems, i.e., systems where there is man involved, where he gets information, where he takes action, and where he stays in a closed-loop-system. If you don't require action with the information from the display, then the problems are somewhat different.

I think that in the case of an aeronautical chart or something that is actually used by someone, it's not too difficult to find out the conditions of use, how it was used, and user-design parameters. The difficulty of designing classroom maps and atlas maps is made more difficult in that use and user situations are not closed-loop-systems or operations.

In any case, where a decision or an action is required, there is no reason why we can't find fundamental design parameters, that is, those related to the use and the use situation. Obviously, the optimum design may not necessarily be what the cartographer thinks the user requires, especially if the cartographer follows fallacious physical and physiological design parameters.

We are finding now, in the talks yesterday and today, that many maps are being developed and used in systems in which man interacts. (See Figure 5). Map information used in these systems includes conventional data and remote sensing observations with these being fed into a total information system. It is assumed that some resource manager has to make a decision. Now the question is -- can this man, as the decision maker, use a bunch of maps and charts piled on a table, no matter how well they are designed. It is now clear that the information from those charts can be more efficiently used in some kind of computer system. Does it really make a lot of difference what kind of cognitive realm the cartographer was in? He doesn't know what kind of information this fellow needs to make his decisions. I propose, such as Joel Morrison talked about this morning, that I would start with the cognitive realm of the cartographer and work back and try to fit the cognitive realm of the cartographer into this system, rather than vice versa.

I believe that in the future increased demands for better decisions on the use of the environment and better information to be used in resource management will require improved digital information management systems. Notice that I did not say that we need better maps. We must have improved systems to integrate map and other information in the user, decision-making environment.

The next three slides are the "strawmen" I referred to earlier. In these, I have tried to discuss maps in terms of information systems. I have tried to categorize the maps and charts and graphics that we make into one of these three

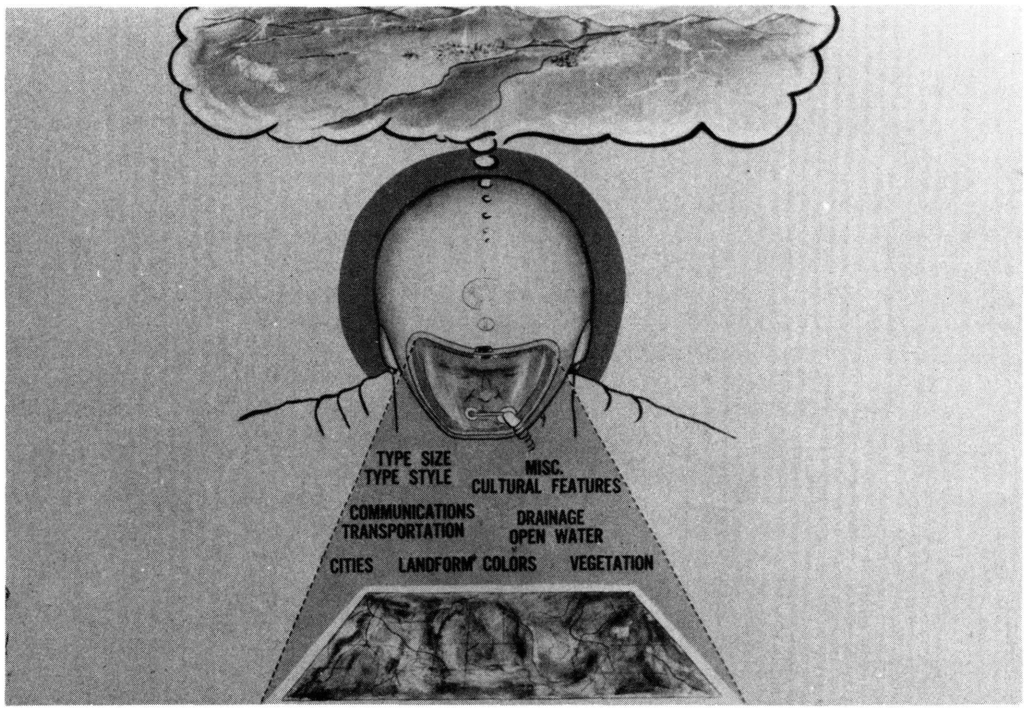

Figure 3

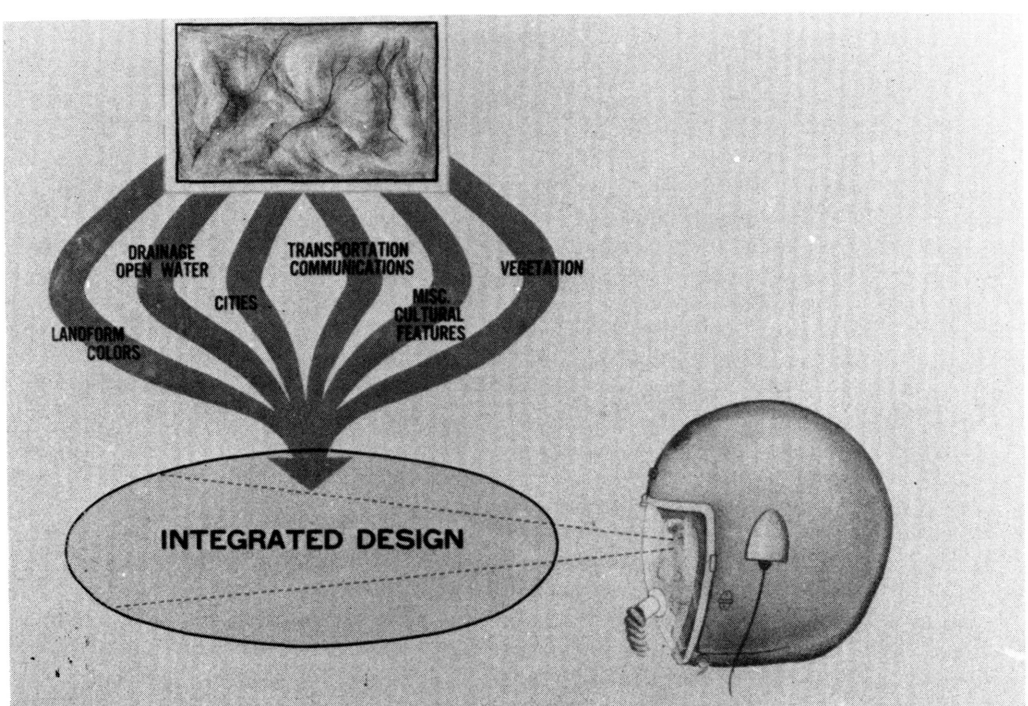

Figure 4

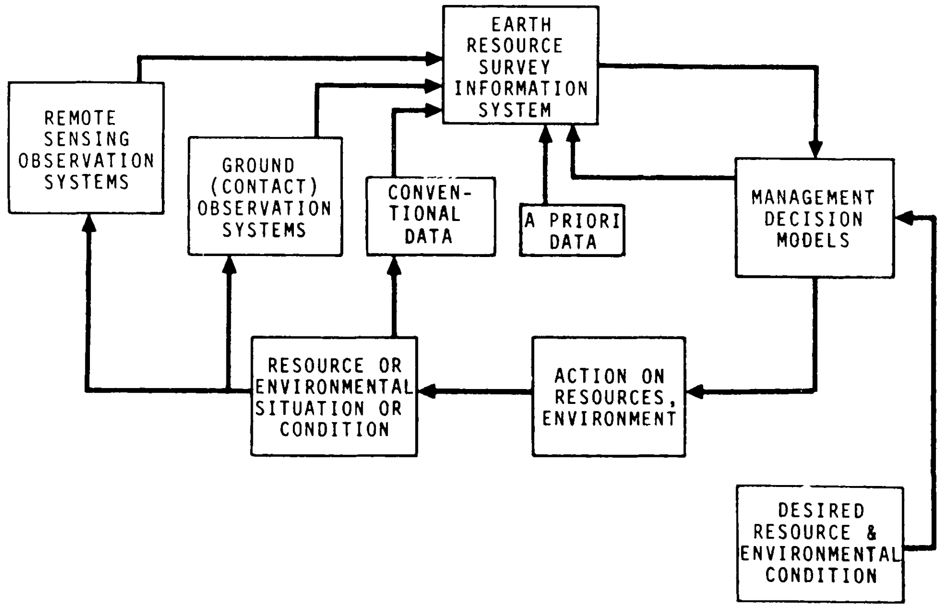

Figure 5

CLASSES OF CARTOGRAPHIC (MAP, CHART, AND GRAPHICAL) DISPLAYS

IN TERMS OF INFORMATION SYSTEM FUNCTIONS

STORAGE

- BASE MAPS

  PLANIMETRIC
  TOPOGRAPHIC
  ORTHOPHOTO MAPS
  ORTHOPHOTO IMAGES

- GEOGRAPHIC (PLACE AND LOCATION) REFERENCE MAPS

  ATLASES
  GAZETTEERS

INFORMATION EXTRACTION

- THEMATIC MAPS (INCLUDING OVER-LAYS TO BASE MAPS)
- GENERAL AND SPECIAL PURPOSE WALL MAPS

  EDUCATIONAL
  RESOURCE INFORMATION
  STATUS INFORMATION

- SPECIAL PURPOSE REFERENCE MAPS AND GRAPHICAL DISPLAYS

  SURVEYS
  STATUSES
  INVENTORIES
  ATLASES
  RELIEF MODELS

- RAILROAD TIMETABLE MAPS

DECISION-MAKING

- ORIENTATION AND NAVIGATIONAL

  ROAD MAPS
  AERONAUTICAL CHARTS
  HARBOR AND COASTAL CHARTS
  SPACE FLIGHT CHARTS AND MODELS (SIMULATIONS AND OPERATIONS)
  MAPS FOR THE BLIND

- TACTICAL USE

  MAPS
  MODELS
  GRAPHICS

- RESOURCE MANAGEMENT

  MANAGEMENT OBJECTIVES
  ALTERNATIVE COURSES OF ACTION
  EVALUATION OF ALTERNATE PLANS
  PLAN SELECTION
  RESOURCE UTILIZATION
  MONITORING OF USE
  MODIFICATION OF MANAGEMENT PLAN

Figure 6

systems (Figure 6). On the left there is the case of maps being simply storage systems. These include U.S.G.S. topoquads, Soil Conservation Service soil maps, etc. Also place name atlases and gazetteers fall in this category. The user simply searches for information in this group.

In the middle section, "INFORMATION EXTRACTION," we have all of our thematic maps, census maps, wall maps, etc., and those such as railroad timetable maps. As in the storage case, the user does not make decisions with these maps (except perhaps when he arrives at his station).

Lastly, on the right as far as decision-making is concerned, I haven't presented an exhaustive list. Here are just three examples for the purpose of illustration. The first heading is orientation, and please note that it includes maps for the blind. Remember that this blind fellow has to make decisions and he has to be right — otherwise he will not end up at his intended location. It is very important that he get correct information from his fingertips. The tactical category of use is obvious and, lastly, I have included resource management. Shown here are the steps the resource manager goes through. I don't know whether these managers want maps or will even use map information. In any case, on the right of this chart is decision-making. The analysis uses are in the middle. The analyst and the manager may not be the same individual, and in fact, in most cases they aren't.

On the previous illustration I categorized the cartographic products which are produced. On the next chart (Figure 7) I'm going to use the same three categories, but now I am going to use those kinds of products in terms of the time and attention that the user must expend in attempting to use those products. In case of

CLASSES OF DISPLAYS IN TERMS OF

USER COMMUNICATION TIME AND ATTENTION

STORAGE	INFORMATION EXTRACTION	DECISION-MAKING
• VIRTUALLY UNLIMITED TIME FOR STUDY, SCALING, AND MEASURING FROM PRECISION PRODUCTS.	• TIME SIGNIFICANT, BUT NOT A MAJOR FACTOR IN STUDY, SCALING, AND MEASURING. PRODUCTS MAY OR MAY NOT MEET NMAS.	• TIME CRITICAL SINCE IN MANY CASES COURSE-OF-ACTION DECISIONS MUST BE MADE QUICKLY AND IN RAPID SEQUENCE. STUDY, SCALING, AND MEASURING WHICH MUST BE DONE VISUALLY PRECLUDE NEED FOR PRECISION PRODUCTS.
• ATTENTION TIME FOR STUDY AND VISUAL COMPARISON ALMOST UNLIMITED.	• ATTENTION TIME FOR STUDY AND VISUAL COMPARISON ONLY SLIGHTLY RESTRICTIVE.	• ATTENTION TIME (VISUAL COMMUNICATION) MUST BE, IN MANY CASES, VIRTUALLY INSTANTANEOUS WITH AS LITTLE ATTENTION TIME AS POSSIBLE SPENT IN STUDY AND COMPARISON.
• ENVIRONMENT OF USE OF LITTLE CONSEQUENCE, OTHER THAN ADEQUATE SPACE AND ILLUMINATION.	• ENVIRONMENT OF USE OF SOME CONSEQUENCE, E.G., CLASSROOM, OFFICE, FIELD, ETC.	• ENVIRONMENT OF USE OF MAJOR IMPORTANCE, E.G., COCKPIT, COMPUTER DISPLAY TERMINAL, ETC.

Figure 7

the information storage product he can take all the time he wants to study scale and conventions. Obviously, they need to be precise, i.e., he needs to know where places are and how high they are above sea level. He can take all the time and use any kind of tools that he wants to. So visual design for momentary communication is not important, or is relatively unimportant. So, poor design doesn't necessarily overtax the fellow who simply wants storage information. The time duration for studying visual comparisons again is almost unlimited. The environment of use just requires a large table and good illumination. In the middle group, time again is not a major factor, neither in studying nor in scaling or measuring. Products may or may not need national map accuracy standards. In most cases they don't have to, because the user of an extractive product (that is usually a generalized and smaller scale product) doesn't need the national map accuracy standards. If he does, he had better go back to the original data and not use the generalized smaller scale map. Attention time for study and visual comparision will be slightly restricting, but, in any event, decisions and actions are not required.

Lastly, environment of use is of some consequence, that is, if it's a classroom, obviously the student in the back of the room has to get the same information as the one in the front of the room. On the right is the decision-making process and this is where the cartographer runs into the problem. Time is critical since, in many instances, course-of-action decisions must be made quickly and in rapid sequence. Studying, scaling, and measuring, which must be done visually, precludes the need for a precision product. If the user must get the information fast, then extreme accuracy is probably not required. Attention time, that is the time for visual communication, must be in many cases virtually instantaneous. As little attention time as possible must be spent in study and comparison. Lastly the environment of use is of major importance — it could be the cockpit of an aircraft, a computer display terminal, or other. If a television display is used, scale and degree of generalization becomes simply a matter of storage capacity, since complex or generalized maps can be generated almost instantaneously.

On the last chart (Figure 8) I have used the same three classes again, but I have tried now to summarize in terms of map, chart, and display design. It is hoped that this figure will indicate where we should spend our time in research. In the first column it should be obvious that if the Department of Defense or other mapping agencies standardize these products, all they are affecting is the storage function. As long as all users are merely interested in stored information, there is no problem in use.

CLASSES OF DISPLAYS IN TERMS OF
MAP, CHART, AND DISPLAY DESIGN

STORAGE	INFORMATION EXTRACTION	DECISION-MAKING
• FEW PROBLEMS ARE ENCOUNTERED IN USE OF CARTOGRAPHIC CONVENTIONS WHICH MUST BE LEARNED AND REMEMBERED BEFORE THEY CAN BE USED, SINCE TIME IS AVAILABLE TO CONSULT LEGEND.	• SOME PROBLEMS ENCOUNTERED IF CONVENTIONS ARE ADHERED TO. TOO MUCH INFORMATION IN ABSTRACT FORM CONFUSES USERS WHO CANNOT CONSULT A LEGEND, E.G. WALL MAPS.	• DESIGN IS CRITICAL, SINCE VISUAL COMMUNICATION MUST BE VIRTUALLY INSTANTANEOUS. ONLY IMMEDIATELY RECOGNIZABLE SYMBOLS ARE USED.
• OPTIMUM DESIGN FOR RAPID COMMUNICATION OF NEEDED INFORMATION OF MINOR IMPORTANCE, SINCE FEW VISUAL COMPARISONS ARE REQUIRED.	• DESIGN IMPORTANT FOR INTENDED PURPOSE BUT VISUAL COMPARISON AND COMMUNICATION DO NOT RESULT IN A DECISION OR ACTION BEING TAKEN.	• DESIGN MUST PROVIDE FOR A MINIMUM AMOUNT OF TIME SPENT IN STUDY AND VISUAL COMPARISON. DISPLAY SHOULD UNBURDEN USER AND NOT BURDEN HIM WITH MORE INFORMATION THAN HE NEEDS.
• MEASUREMENTS AND SCALING ARE ACCOMPLISHED USING PRECISION INSTRUMENTS AS REQUIRED IN ANY ADEQUATE WORK SPACE.	• MEASUREMENTS AND SCALING NOT AS IMPORTANT SINCE ENVIRONMENT OR USE PRECLUDES THE NEED. VISUAL COMPARISONS IMPORTANT BUT AGAIN, NO DECISION OR ACTION WILL RESULT.	• PRECISE (IN TERMS OF USE) INFORMATION MUST BE COMMUNICATED VISUALLY. DISPLAY EFFECTIVENESS CRITICAL IN TERMS OF USE ENVIRONMENT.

Figure 8

In the second column, in what I have called information extraction, if you adhere to too many conventions, people will have trouble using these products. Wall maps are a good example. If the student in front can see the legend and if the student in back cannot, they may not receive the same information. You have to be careful, since in this group design is important, but it is not critical. Lastly measurements and scaling are somewhat important, since visual comparison is required; but again, no decision or action will result from this category of products. These are products that end up after analysis, but haven't been used as yet in a management or action context. Over in the right column are the decision makers. Here design is critical, visual communication must be unequivocal and virtually instantaneous. Only immediately recognizable symbols should possibly be used to communicate information in a minimum amount of time, since, in many cases, there is little time for study and comparision. The display should unburden the user and should not burden him with more information than he needs. I saw a bunch of people at this meeting spending ten to fifteen minutes trying to understand the color code on one of the new maps in the census room. The logic behind the color code may have been arrived at systematically, but I can see what is going to happen to the average citizen who attempts to relate color to quantities of something. If people here at this meeting don't understand, or it takes fifteen minutes to a half hour to understand the code, what will happen to the average man?

Lastly, products in this category must be precise. And I say precise in terms of the user, not precise in terms of the cartographer. Precise information must be communicated visually and the display effectiveness is critical in terms of the use environment. If the designer doesn't consider the use environment, or, if he doesn't consider precision in terms of the use of the information to be communicated, then the cognitive realm is left out in left field. If the cartographer doesn't start with the user and a use situation before he plans the design, there is a question as to whether he ever approaches a real "cognitive" realm in which the user thinks in terms of a mental map.