AD-A217 900

Netherlands
organization for
applied scientific
research

IZF

TNO Institute for Perception

I.D. 89-1057

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

90 02 0? 105

Netherlands
organization for
applied scientific
research

TNO-report

TNO Institute for Perception

P.O. Box 23
3769 ZG Soesterberg
Kampweg 5
3769 DE Soesterberg, The Netherlands

Fax +31 3463 5 39 77
Phone +31 3463 5 62 11

IZF 1989-36

J.M.C. Schraagen

NAVIGATION IN UNFAMILIAR CITIES: A REVIEW OF THE LITERATURE AND A THEORETICAL FRAMEWORK

2

The work reported in this publication is part of the project "Generic Intelligent Driver Support Systems" (GIDS) carried out under contract DRIVE V1041 of the European Community, in which the Traffic Research Centre, University of Groningen acts as prime contractor and the TNO Institute for Perception, the Swedish Road & Traffic Research Institute (VTI), University College at Dublin, Renault, INRETS-LEN, Philips Research Laboratories, YARD Ltd., MRC Applied Psychology Unit, Saab-Scania, Delft University of Technology, DEVTECH International BV and the University of Tübingen are represented as partners. The opinions, findings and conclusions expressed in this report are those of the authors alone and do not necessarily reflect those of the EC or of any organization involved in the project.

Number of pages: 27

CONTENTS Page

Report No.: IZF 1989-36

Title: Navigation in unfamiliar cities: a review of the literature and a theoretical framework

Author: Drs. J.M C. Schraagen

Institute: TNO Institute for Perception

Date: October 1989

No. in Program of Work: 733.1

SUMMARY

This report is based on a literature review in which an attempt is made to identify those concepts and specific studies within cognitive science, that have direct relevance to navigation in unfamiliar cities. In particular, issues are discussed related to the strategies and representations used by drivers who have to find their way in unfamiliar cities. The interaction between the way spatial knowledge is represented and the search strategy used, is emphasized. A normative task analysis is proposed. The main goal of the report is to generate predictions to be tested in a subsequent field experiment.

Rap.nr. IZF 1989-36 Instituut voor Zintuigfysiologie TNO, Soesterberg

Navigeren in onbekende steden: een literatuurstudie en een theoretisch kader

J.M.C. Schraagen

SAMENVATTING

Dit rapport is gebaseerd op een literatuuronderzoek waarin getracht is die begrippen en specifieke onderzoeken binnen de cognitieve psychologie te identificeren die van direct belang zijn voor het navigeren in een onbekende stad. In het bijzonder wordt aandacht besteed aan aspecten die te maken hebben met de strategieën en representaties die automobilisten gebruiken bij het vinden van hun weg in onbekende steden. De interactie tussen de wijze waarop ruimtelijke kennis is gerepresenteerd en de gebruikte zoekstrategie, wordt benadrukt. Een normatieve taakanalyse wordt voorgesteld. Het belangrijkste doel van het rapport is voorspellingen te genereren die in een hierop volgend veldexperiment getoetst kunnen worden.

1 INTRODUCTION

Finding one's way in an unfamiliar city can be a difficult task, particularly when one has to attend to other traffic at the same time. Getting to know the city beforehand, by studying maps or asking people familiar with the city to point out the way, may make the task somewhat easier. Still, one frequently has to stop to check one's position, since information studied beforehand is often partially forgotten.

The task would be somewhat easier if the driver could have permanent access to several kinds of information necessary for navigating in an unfamiliar city. One solution would be a simple piece of paper, where the driver has written down names of roads to be followed, or has drawn a sketch map of the city. This solution may still be very effective, but it is limited in the information it offers. Another solution, which is now technically feasible, would be a navigation system, an electronic aid that offers the driver various kinds of information upon request.

A question that arises with navigation systems is what kinds of information should be presented to the driver. In order to be able to answer this question, one first needs to find out how drivers actually navigate in an unfamiliar city. This gives an indication of the amount and type of information used. After this, one may try to optimize the human information processing by manipulating the amount and type of information presented to the driver, taking into account the driver's computational limits and his or her representations and strategies.

This report serves as a "Technical Annex" to the first deliverable of the Workpackage NAV within DRIVE Project V1041. The project is known under the name of GIDS, which stands for Generic Intelligent Driver Support. The overall objective of the project is to determine the requirements and design standards for a class of intelligent co-driver systems which will be maximally consistent with the information requirements and performance capabilities of the human driver. We are here concerned with one subsystem of such a co-driver system, namely the navigation subsystem.

The goal of this report is to give an overview of possible representations and strategies that drivers may use when navigating in an unfamiliar city. This overview is partly based on a review of the literature, and partly on theoretical considerations. We will sum up the major conclusions in the form of predictions, to be tested in a subsequent field experiment.

2 A COGNITIVE SCIENCE APPROACH TO NAVIGATION

Route finding in an unfamiliar city can be considered as a form of problem solving, since it is not immediately clear to a driver new to a city how to reach his or her goal, in this case a particular destination. Thus, the driver is confronted with a problem (cf. Duncker, 1945). In order to solve this problem, drivers must exercise their intelligence. Since it is unfeasible to randomly search in a city for a particular destination, drivers search heuristically, i.e. they search selectively for a route that will bring them closer to their destination. The search is carried out in a problem space (Newell and Simon, 1972). The problem space is a representation of the task environment. It is important to note that the representation is not uniquely determined, but only constrained by the task environment. A driver searches in his or her problem space by means of a strategy. The strategy, too, is not uniquely determined, but only constrained by task environment and problem space. This allows for different problem spaces and strategies for different subjects in the same task domain.
Thus, to a driver unfamiliar with a city, the city is a complex problem environment, in which the destination is reached by a process of heuristic search. The heuristic search is carried out in a problem space, which is a representation of the environment. The important theoretical concepts here are heuristic search and problem space. We will discuss these concepts in more detail below.

2.1 Heuristic search

How is the heuristic search accomplished? First of all, by using information stored in memory to choose more promising over less promising routes. The information stored can of necessity only be very abstract, since the driver does not possess any knowledge of the city he or she is navigating in. So, the information that can be used concerns abstract information about cities in general, about the general position of the destination (North, South, etc.), about strategies that have proven useful in the past in similar situations, etc. Secondly, heuristic search is accomplished by extracting from the problem environment new information about regularities in its structure that can similarly guide the search. For example, a driver may note that the network of major streets in a city forms a pattern, such as a cartwheel with spokes and rims, or some rectangular grid pattern. The driver may decide to stay on that pattern, as long as it will lead him or her closer to the destination.

The task we are concerned with here, navigation in an unfamiliar city, precludes any prior navigation experience with the city. Therefore, any knowledge about the city is in declarative rather than procedural form (Anderson, 1983). Declarative knowledge is knowledge *that*, while procedural knowledge is knowledge *how*. As long as knowledge is not proceduralized, declarative knowledge has to be interpreted by weak problem solving methods, such as analogy, means-ends analysis, or general geometric inferences (cf. Kuipers, 1978). Weak problem solving methods are called "weak" because they do not take advantage of domain characteristics. They are very general strategies for searching the problem space. As an example of a geometric inference, most people know that when a road is blocked, and the road is a side of a rectangle, then the destination can also be reached by driving the other three sides of the rectangle. People can also figure out the direction from B to C, given the direction from A to B and the direction from A to C. Presumably, people have acquired this knowledge in elementary school.

Which weak methods can apply and how they apply is determined by the declarative knowledge that is encoded about the problem domain (Anderson, 1987). In the case of navigation, the declarative knowledge encoded is determined by studying maps, receiving instructions, and so on. The actual form of the declarative knowledge determines the weak method adopted. For instance, if the driver has not explicitly encoded four roads as the four sides of a rectangle, he or she will not be able to use the general geometric inference rule mentioned above. As another example, if a driver has not explicitly encoded the general direction of the destination (e.g. North, South, or a somewhat vaguer indication), he or she will not be able to determine whether progress is being made toward the goal, at least when no map is available. In this case, the driver will not be able to use means-ends analysis, which states that one should choose that route that reduces the difference between the current state and the goal state (destination) the most. Generally, however, in situations where novel problems with specific goals have to be solved, as is the case with navigation in an unfamiliar city, the strategy of means-ends analysis is frequently employed (Greeno and Simon, 1988).

An advantage of using weak methods is that they are very flexible, since they can apply in a wide range of domains. However, the costs of this flexibility are slowness and error-proneness. This is because declarative knowledge has to be held in working memory in order for the weak methods to be able to match it. Acquiring knowledge from a map of an unfamiliar city and using this knowledge may thus be expected to be a slow and error-prone process, with a lot of forgetting of information, due to working memory limitations. In order to overcome these limitations, people may be expected to frequently rehearse the information to be remembered, to reconsult maps or notes they have written down, to obtain verbal directions, or use any other means for preventing them from getting lost.

2.2 Problem space

Generally, drivers need information when the representation they have formed of the city is incomplete. This is always the case when navigating in an unfamiliar city, even after extensive preparation. The newly formed representation is too brittle, since it is not connected with any visual cues from the environment. This is in sharp contrast with a driver very familiar with a city, such as a taxi driver (Chase, 1983). With increasing familiarity, visual cues begin to play an increasingly important role, such that they automatically retrieve the appropriate choice of route from the long-term memory knowledge base (Chase, 1983). It has been shown in a wide variety of domains that a large knowledge base consisting of familiar perceptual patterns, together with associated actions, constitutes a large part of what is sometimes referred to as the expert's "intuition" (see Schraagen, 1986, for a review). For such a mundane skill as navigating, this comes as no surprise to most people. This may be why people skillful in finding their way in a city they are very familiar with, are usually not being credited with "intuition". The underlying processes are no different, however, in the case of navigation than in the case of a grandmaster in chess, who can recognize thousands of patterns of pieces (De Groot, 1965; Chase and Simon, 1973).

2.3 Computational limits

The driver's behavior is not only determined by his or her goals, representations, and strategies, but also by computational limits. These are, for instance, limits on the capacity of short-term memory, the presence or absence of external memory aids, and the speed with which new information can be stored. Short-term memory limits force the driver to be basically serial in his or her behavior, at least at the level of goal-oriented activity. This means that only one attention-demanding task can be carried out at the same time. Finding a destination in an unfamiliar city certainly is an attention-demanding task. Maneuvering the car is another attention-demanding task, at least when the driver is relatively unskilled, and/or the traffic is heavy. Therefore, the limits on short-term memory may force an unskilled driver who is navigating in an unfamiliar city to switch between navigation and maneuvering.

The presence or absence of external memory aids (maps, verbal instructions, notes, signs) may also be a limiting factor. In the absence of any external memory aids, the driver has to rely on information stored in long-term memory, in order to be able to search heuristically. With the help of external memory aids, the driver can form a representation of the environment and extract new information from the environment. When an external memory aid is not continuously available while driving, as with a map or verbal instructions, the driver has to remember the information. Since there is usually too much information to remember, and not all information can be transferred to long-term memory, some information has to be kept active in short-term memory. Because of the limited capacity of short-term memory, and because other tasks, such as maneuvering, also require attention, some information will tend to be forgotten.

An overview of how subjects should carry out the particular navigation task considered here, is given in Appendix A in the form of a normative task analysis. This normative task analysis is based on the work of McKnight and Adams (1970), supplemented by elements from Thorndyke and Stasz' (1980) scheme for coding verbalizations from subjects' protocols while studying maps.

3 A QUANTITATIVE ANALYSIS OF NAVIGATION PLANNING

So far, it was stated that navigation in an unfamiliar city can be viewed as a heuristic search process in a problem space. We have indicated some of the heuristics that drivers may use, and we have also discussed some evidence for a hierarchical representation of the general road knowledge. However, we can be a little more precise about the size of the problem space, and the amount of search required given various sources of knowledge.

A problem space consists of all possible states that may be obtained by applying certain operators to those states. In the case of navigation, the states of the problem are street intersections, and the operators are sections of road between intersections. Consider the medium-sized Dutch city of Amersfoort (approx. 100,000 inhabitants), with approximately 1,000 street intersections, or states. In the case where no knowledge is available to reduce search effort, a goal state can only be reached by brute-force search. The complexity of brute-force search depends on two parameters of the problem, the branching factor and the depth. The branching factor (b) of a problem is the average number of new states that can be generated from a given state by the application of a single operator, and the depth (d) of a problem instance is the length of the shortest solution path from the initial state to a goal state.

Since most intersections have three or four sections of road connected to them, let us assume that on average the branching factor (b) is equal to 3.5. Furthermore, let us assume that the depth (d) of a particular problem instance (finding the shortest route from the Stichtse rotonde to the Swammerdamstraat) is 22. Using a breadth-first search, this yields 3.5^{22} (b^d) possible solutions, which is approximately 10^{12} possible solutions.

If we assume the driver possesses some hierarchical knowledge about different types of roads, we may view the search as being carried out in an abstract search space, consisting of a subset of the states in the original problem space. In this example, the driver might use a map and only focus on the roads indicated in yellow. Note that this is a feasible strategy, even for a driver unfamiliar with a city, since it only draws upon general road knowledge and experience from previous navigation trials. Indeed, people's strategies for finding unfamiliar routes typically include finding main roads, and applying divide-and-conquer as well as depth-first search (Elliott and Lesk, 1982). Instead of the 1,000 possible states in the original problem space, there are now only 20 possible states in the abstract problem space. For the example mentioned above, there now result approximately 12 million possible solutions. Thus, adding a little knowledge reduces the search space with a factor 10^5. In other problem instances, where a lot more use can be made of the hierarchical network than in the particular example considered here, far greater savings can be observed.

Abstract states and abstract operators can also be created simply by putting up road signs (Korf, 1987), indicating, for example, neighborhoods in cities. Using neighborhoods as an extra level of abstraction reduces the search space even more, since the driver now knows how to get from one neighborhood to another, and the search only has to be carried out in the particular neighborhood where the destination is. Korf (1987) has shown that abstraction hierarchies can reduce exponential problems, such as navigation, to linear complexity, and that, generally, the more levels of abstraction, the more search will be reduced. If the driver can make use of external memory aids, the memory space requirements of these abstract problem spaces are negligible. If the driver cannot make use of any external memory aids, he or she will still try to minimize working memory load, for example, by staying on one road as long as possible.

4 SOME EMPIRICAL OBSERVATIONS

There is some empirical evidence concerning the representations and strategies used by subjects who have to find their way in unfamiliar cities. We will first consider some of the general knowledge drivers possess, after which three types of representations (or problem spaces) will be distinguished that have been empirically observed.

4.1 General knowledge

Drivers do not enter an unfamiliar city as a tabula rasa: they have extensive knowledge of cities they once have visited, and thus have certain expectations about cities in general. For example, they know that churches generally are to be expected in the city entre, while swimming pools are to be situated away from the center, at least in the somewhat older Dutch cities. This general knowledge about cities may help the driver in unfamiliar cities to situate certain landmarks. Some empirical evidence to support this conjecture comes from a study by Devlin (1976).

Drivers new to a city not only know where certain landmarks and streets are to be located, they also have general knowledge about road types, e.g. main roads and secondary roads. They know that main roads are generally faster and less stressful. Therefore, even if a particular road is unfamiliar, it may still be meaningful to a driver. The road may be classified as being a "secondary road", and the resulting action is: "should be avoided".

This general road knowledge is organized hierarchically, with the major roads (base network) on top, and the most local roads (secondary network) on the bottom. It has been shown that drivers who are unfamiliar with a particular area, prefer to stay on the major roads as long as possible, and only move to a more local road type when absolutely necessary (Elliott and Lesk, 1982; Streeter and Vitello, 1986). For drivers who are familiar with the area, the road hierarchy flattens. These drivers simply take the fastest route, irrespective of road type (Streeter and Vitello, 1986). Thus, expert taxi drivers use the secondary network whenever they can (Chase, 1983). This is in

contrast to what Pailhous (1969) has found, namely that expert taxi drivers used the secondary network only to get around a barrier, and tried to get back to the base networks as quickly as possible.
The hierarchical nature of spatial knowledge allows people to infer relationships they have not stored directly. For instance, determining the relationship between two cities in different countries may be achieved by noting the location of each city and the location of the countries relative to each other. From this knowledge, the geographical position of the two cities relative to each other may be determined. However, this process of inference making will sometimes lead to errors, namely in those cases where the location of the countries has been *normalized*. Normalization is a familiar type of error in people's spatial representations (Stevens and Coupe, 1978; Chase and Chi, 1981). It means that people tend to impose a grid structure on their memory representations, which leads to an underestimation of curves and angles. Parisians, for example, underestimate the actual curvature of the Seine River (Milgram and Jodelet, 1976). The same normalization error may occur in the case of countries, e.g. people think that all of Switzerland is to the east of France, but certain cities in France are to the east of certain cities in Switzerland. This may result in distortions in judged spatial relations that are a consequence of the hierarchical nature of the city-country relation.

4.2 Types of spatial knowledge

Following Thorndyke and co-workers (Thorndyke and Stasz, 1980; Thorndyke and Hayes-Roth, 1982; Thorndyke and Goldin, 1983; see also Siegel and White, 1975), we propose three types of spatial knowledge, organized hierarchically:

4.2.1 Landmark or sensorimotor knowledge

This knowledge represents information about the visual details of specific locations in the environment, connected with actions. These are the traveler's input-output relations with the environment, based on an alternating sequence of views (current sensory inputs) and actions (Kuipers, 1978; 1988). Examples of this kind of knowledge are towers, bridges, railroads, churches, statues, or any other kind of salient object. Saliency need not be restricted to visually distinctive views, but can be extended to include functional views that may have a special significance for certain individuals, e.g. a bus stop, a car wash, the hospital, the shopping mall, etc. (Devlin, 1976). Even a collection of aural, tactile, and olfactory stimuli may be considered a view for a blind traveller.

There is some evidence to suggest that people initially learn the relative position of landmarks in space and that later on path structures are elaborated within the initial landmark network (Evans, Marrero, and Butler, 1981). Increasing familiarity with certain landmarks makes these landmarks *reference points* that serve as organizing loci for other landmarks (Sadalla, Burroughs, and Staplin, 1980).

4.2.2 **Procedural or route knowledge**

This knowledge represents information about the sequence of actions required to follow a particular route. These are "learned and stored procedures defined in terms of sensorimotor primitives for accomplishing particular instances of place-finding and route-following tasks" (Kuipers, 1988, p.26). Route knowledge is knowledge from an ego-centered frame of reference, and thus corresponds directly to what one sees as one follows a route. This is the kind of knowledge expert taxi drivers use when they leave the base road network, and start driving on the secondary road network (Pailhous, 1969). An example of this kind of knowledge is a sequence of verbal directions, such as: "Turn right at the church and expect a large boulevard; take the third intersection to the left, and expect a small street with shops". When routes are very familiar, such verbal directions cannot be given very accurately, although the route can be driven flawlessly, giving rise to the "I could take you there, but I can't tell you how!" phenomenon. The knowledge has become proceduralized, i.e. fast, highly situation-specific, and not available for verbalization (Anderson, 1983). It can only be triggered by directly perceiving certain features in the environment. Kuipers (1983) has argued that storing links in long-term memory associating a current view with a current action is much more probable than storing a previous view, the action taken there, and the resulting view, due to the greater working memory load in the latter case. This would explain why people can reconstruct a route from memory *while travelling in* the environment, but not (or with greater difficulty) *in the absence of* the environment.

Of course, drivers unfamiliar with a city do not possess this proceduralized knowledge. Directions for driving are stored declaratively, hence can only be accessed by interpretive procedures. For instance, the direction: "Turn right at the church" can only be executed correctly, when the subject classifies a building at a certain point on the route as being a church. Note that this may be quite difficult for atypical churches (modern churches sometimes look more like schools).

The same problem arises when one has encoded the direction: "Turn left at a major intersection" from a map, and in reality the intersection looks quite different from what one had expected. One of the major problems when studying maps is building up an efficient representation that allows one to make the correct choices. The less ambiguous the elements of such a representation, the less likely are navigation errors. Examples of unambiguous elements are street names and road signs.

Knowledge of a route is focused on key loci representing choice points. This implies that individuals will code more information at choice points than at other points, where no major action is mandated (Golledge, Smith, Pellegrino, Doherty, & Marshall, 1985). Knowledge of these choice points is necessary for concatenating them into a unified structure representing a "route". Golledge et al. (1985) also found that more information is encoded for objects at which errors in decision-making have occurred. Since errors are more likely to occur at more complex choice points, this is probably why these choice points are better remembered. Routes appear to be hierarchically organized, with more complex choice points higher in the hierarchy. Errors occur less frequently and linger longer at points that occupy lower levels of the hierarchy.

4.2.3 Survey knowledge

This knowledge represents object locations and inter-object distances linked by topological or metric relations. Topological relations are generally acquired prior to metric relations. Examples of topological relations are: connectivity, containment, and order. Examples of metric relations are: relative distance, relative angle, and absolute angle and distance with respect to a frame of reference, as on a conventional map. Accordingly, survey knowledge can be acquired directly by studying a map, as drivers unfamiliar with a city often do. However, repeated navigation in an environment also leads to the development of survey knowledge (Siegel and White, 1975; Evans, Marrero, and Butler, 1981). Extended navigation experience results in a more flexible and complete spatial representation than extended map study (Thorndyke and Hayes-Roth, 1980). Thus, a complete and accurate lower-level map improves the interpretation of observations and the creation of the higher levels of the map (Kuipers, 1988).

Survey knowledge is more flexible than route knowledge. It may be used when one is lost, since in that situation route knowledge, perfect while on course, suddenly becomes nearly meaningless. Therefore, where the likelihood of errors is greater, survey knowledge becomes preferable. A potential problem with survey knowledge, however, is its sensitivity to incompatibility of orientation. When driving in a southern direction, with a north-up map, a left turn on the map is a right turn in reality, and vice versa. In such a situation, at least some people have great difficulty reorienting the map, when it is learned in a north-up direction (Wetherell, 1979). Therefore, a map that is aligned (that is, whose features are parallel to those in the terrain) is easier to use than one that is unaligned (Levine, Jankovic, and Palij, 1982).

Thus, although survey knowledge provides the most powerful problem-solving capabilities, it is also the most vulnerable to resource limitations. The landmark and procedural levels are frequently capable of solving navigation problems, although perhaps providing a less optimal or less informative solution. In the specific case of driving in an unfamiliar city, landmark, procedural, and survey knowledge are only available when previously extracted from a map or from verbal instructions. The driver can also use very general survey knowledge that is already stored in LTM.

4.3 Experience

Another factor affecting navigation performance may be driving experience. Experienced drivers are probably better able to navigate while driving than novice drivers, since the driving task itself demands less of their attention. They can therefore devote more of their attention to the navigation information they have to use. If experienced drivers have also navigated more in unfamiliar cities than novice drivers, which need not necessarily be the case, then they may have learned from experience that certain kinds of information are more useful than other kinds of information. Also, highly mobile individuals (e.g. airline pilots who have been based in many cities during their career), when asked to draw regional or town maps, are more likely to draw maps which contain more features and are highly organized than are medium or low-mobility individuals (Murray and Spencer, 1979). Highly mobile individuals presumably have developed abstract schemata for the layout of towns and regions.

Experienced drivers may also use certain heuristics, gained from experience, such as: plan extensively beforehand, and use the plan while driving, or: stay on main roads as long as possible. These heuristics may guide them to their destination more quickly and/or with less stress (Michaels, 1966) than novice drivers, even when both groups are unfamiliar with the city they drive in. In other words, experienced drivers possess general navigation schemata or travel plans (Gärling, Böök, and Lindberg, 1984), consisting of goals, general knowledge of preferable routes and heuristics. They will use these schemata to store and retrieve information gained before and during navigation. Generally, these schemata may be used for anticipating novel situations, thereby minimizing working memory load. Therefore, including novice and experienced drivers seems to be an interesting manipulation.

4.4 Individual differences

Why do some people acquire spatial knowledge faster or better, holding learning time constant? The theoretical framework sketched above suggests that some people may be better in encoding spatial information than others. This may be because of their better-structured general schemata for interpreting new spatial information, better learning procedures, some primary spatial ability, or some other factor, yet unknown.

In an experiment by Thorndyke and Stasz (1980) on the procedures people use to acquire knowledge from maps, good map learners differed from poor map learners in both learning procedures and visual memory ability. Good map learners first segmented and focused systematically on subsets of information from the map, whereas poor learners sampled randomly. Good learners reported constructing in memory and rehearsing a visual image of the maps. They also elaborated and refined their knowledge of spatial location by noticing and encoding explicit shapes (e.g. a street that curved) or spatial relations among two or more map elements (e.g. "Victoria Avenue is below the golf course and parallel to Johnson"). Poor learners often lacked procedures for learning the spatial information. Good learners knew which elements were as yet unlearned and searched for and focused on that information. Poor learners evaluated a significantly smaller proportion of unlearned elements, and instead spent study time confirming that they knew certain information. Thorndyke and Stasz (1980) also found that differences among experienced map users could be attributed to differences in their study procedures, and not to their familiarity with maps. As an aside, it is interesting to note the similarity between Thorndyke and Stasz' results and the results of a recent study by Chi, Bassok, Lewis, Reimann, and Glaser (1989), who were interested in good and poor learners' strategies in studying physics textbook examples. They found that the "Good" students in their sample had superior self-monitoring skills compared to "Poor" students. This correspondence between two highly dissimilar domains reinforces the idea that there are some general learning procedures, or weak methods (e.g. divide-and-conquer), that people may use in various domains.

Thorndyke and Goldin (1983) have argued that map using and spatial knowledge acquisition tasks require independent sets of skills. They base this conclusion on a study in which good and poor mappers learned a map perfectly and then selected and navigated a number of routes. No differences were found between good and poor mappers. In real-life situations, however, people are never asked to learn a map perfectly. This means that when people have to find their way by means of a map, there will always be individual differences in navigation performance due to deficient spatial knowledge acquisition strategies on the part of the poor mappers.

We may tentatively conclude that individual differences in spatial knowledge acquisition emerge most clearly on tasks that require the encoding of spatial information and the manipulation of spatial information in memory (see also Thorndyke and Goldin, 1983). Persons with a high "cognitive mapping skill" use better strategies for acquiring spatial knowledge, and have higher spatial abilities as measured by standard paper-and-pencil tests. Thorndyke and Stasz (1980) found that they could successfully teach effective strategies for learning spatial information, but only to subjects with high visual memory ability.

5 CONCLUSIONS

In a recent review of the literature on environmental perception and cognition, Gärling and Golledge (1989) concluded: "Studies of the acquisition of cognitive maps and place images, and of spatial orientation and navigation are clearly underrepresented in large-scale environments" (p. 34). Although we have reviewed some studies that seemed relevant to the issue of navigation in unfamiliar cities, we agree with Gärling and Golledge's traditional plea for more research. This report may be concluded, then, by making some predictions about phenomena likely to be observed in a field experiment investigating what kinds of information drivers need when navigating in an unfamiliar city. In order to investigate their information needs, we will study the strategies and representations used by two groups of novice and experienced drivers. The following predictions can be made:

1) Both novice and experienced drivers will frequently rehearse the information acquired; they will sometimes miss landmarks and as a

consequence drive in the wrong direction. Navigation errors are particularly likely to be made when cues in the environment do not match the subjects' representation of the cues. These errors are likely to be remembered later, at least when they occur at complex choice points at which a lot of information is encoded.

2) Subjects will not be able to remember more than three or four items (e.g. street names, landmarks), unless some hierarchical representation is used to store and retrieve the items. Experienced drivers will be able to devote more of their attention to navigating, which will show up in less forgetting of information, hence fewer map consultations, fewer navigation errors, faster driving, and faster getting to the destination.

3) When planning their routes by use of maps, subjects store mainly landmark and route knowledge. The efficiency with which they navigate depends to a large extent on the type and amount of information extracted from the map, and on spatial ability. Large individual differences may be observed here.

REFERENCES

Anderson, J.R. (1983). The architecture of cognition. Cambridge, Mass.: Harvard University Press.

Anderson, J.R. (1987). Skill acquisition: Compilation of weak-method problem solutions. Psychological Review, 94, 192-210.

Chase, W. (1983). Spatial representations of taxi drivers. In D. Rogers and J.A. Sloboda (Eds.), The acquisition of symbolic skills (pp. 391-405). New York: Plenum Press.

Chase, W. and Simon, H. (1973). The mind's eye in chess. In W. Chase (Ed.), Visual information processing (pp. 215-281). New York: Academic Press.

Chi, M.T.H., Bassok, M., Lewis, M.W., Reimann, P., & Glaser, R. (1989). Self-explanations: how students study and use examples in learning to solve problems. Cognitive Science, 13, 145-182.

Devlin, A.S. (1976). The "Small Town" cognitive map: Adjusting to a new environment. In G.T. Moore and R.G. Golledge (Eds.), Environmental knowing: Theories, research, and methods (pp. 5866). Stroudsburg, PA.: Dowden, Hutchinson, and Ross.

Duncker, K. (1945). On problem solving. Psychological Monographs, 58, (Whole No. 270).

Elliott, R.J. and Lesk, M.E. (1982). Route finding in street maps by computers and people. In Proceedings of the National Conference of the American Association for Artificial Intelligence (pp. 258-261). University of Pittsburgh, PA.

Evans, G.W., Marrero, D.G. and Butler, P.A. (1981). Environmental learning and cognitive mapping. Environment and Behavior, 13, 83-104.

Gärling, T., Böök, A. and Lindberg, E. (1984). Cognitive mapping of large-scale environments: The interrelationship of action plans, acquisition, and orientation. Environment and Behavior, 16, 3-34.

Gärling, T., and Golledge, R.G. (1989). Environmental perception and cognition. In E.H. Zube and G.T. Moore (Eds.), Advances in environment, behavior, and design (Vol. 2) (pp. 203-236). New York: Plenum Press.

Golledge, R.G., Smith, T.R., Pellegrino, J.W., Doherty, S., and Marshall, S.P. (1985). A conceptual model and empirical analysis of children's acquisition of spatial knowledge. Journal of Environmental Psychology, 5, 125-152.

Greeno, J.G. and Simon, H.A. (1988). Problem solving and reasoning. In R.C. Atkinson, R.J. Herrnstein, G. Lindzey, and R. Duncan Luce (Eds.), Stevens' handbook of experimental psychology (second edition) (pp. 589-672). New York: Wiley.

Groot, A.D. de (1965). Thought and choice in chess. The Hague: Mouton.

Korf, R.E. (1987). Planning as search: A quantitative approach. Artificial Intelligence, 33, 65-88.

Kuipers, B.J. (1978). Modeling spatial knowledge. Cognitive Science, 2, 129-153.

Kuipers, B. (1983). Modeling human knowledge of routes: Partial knowledge and individual variation. Proceedings of the National Conference on Artificial Intelligence (pp. 216-219). Los Altos, CA.: William Kaufmann.

Kuipers, B.J. and Levitt, T.S. (1988). Navigation and mapping in large-scale space. AI Magazine, 9(2), 25-43.

Levine, M., Jankovic, I.N., and Palij, M. (1982). Principles of spatial problem solving. Journal of Experimental Psychology: General, 111, 157-175.

McKnight, J. and Adams, B.B. (1970). Driver education task analysis; Volume 1: task descriptions. Human Resources Research Organization Technical Report 70-103.

Michaels, R.M. (1966). Attitudes of drivers toward alternative highways and their relation to route choice. Highway Research Record Nr. 122, 50-74.

Milgram, S. and Jodelet, D. (1976). Psychological maps of Paris. In H.M. Proshansky, W.H. Ittelson, & L.G. Rivkin (Eds.), Environmental Psychology (2nd ed.). New York: Holt, Rinehart, & Winston.

Murray, D. and Spencer, C. (1979). Individual differences in the drawing of cognitive maps: the effects of geographical mobility, strength of mental imagery and basic graphic ability. Transactions, Institute of British Geographers, 4, 385-391.

Newell, A. and Simon, H.A. (1972). Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall.

Pailhous, J. (1969). Representation de l'espace urbain et cheminements. Le Travail Humain, 32, 87-140; 239-270.

Sadalla, E.K., Burroughs, W.J., and Staplin, L.J. (1980). Reference points in spatial cognition. Journal of Experimental Psychology: Human Learning and Memory, 6, 516-528.

Schraagen, J.M.C. (1986). Expert-novice differences and their implication for knowledge elicitation techniques. IZF Report 1986-34. Soesterberg: TNO Institute for Perception.

Siegel, A.W. and White, S.H. (1975). The development of spatial representations of large-scale environments. In H.W. Reese (Ed.), Advances in child development and behavior (pp. 9-55). New York: Academic Press.

Stevens, A. and Coupe, P. (1978). Distortions in judged spatial relations. Cognitive Psychology, 10, 422-437.

Streeter, L.A. and Vitello, D. (1986). A profile of drivers' map-reading abilities. Human Factors, 28, 223-239.

Thorndyke, P.W. and Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. Cognitive Psychology, 13, 407-433.

Thorndyke, P.W. and Stasz, C. (1980). Individual differences in procedures for knowledge acquisition from maps. Cognitive Psychology, 12, 137-175.

Thorndyke, P.W. and Goldin, S.E. (1983). Spatial learning and reasoning skill. In H.L. Pick and L.P. Acredolo (Eds.), Spatial orientation: Theory, research, and application (pp 195-217). New York: Plenum Press.

Wetherell, A. (1979). Short-term memory for verbal and graphic route information. Proceedings of the Human Factors Society-23rd Annual Meeting.

Date: October 2, 1989

Drs. J.M.C. Schraagen

Appendix A

Normative task analysis for one particular navigation task: finding a route in an unfamiliar city.

1.0 Planning a route from A to B in an unfamiliar city.

1.1 Locate present position

1.1.1 Locate appropriate square on map
1.1.2 Note part of town
1.1.3 Note address
1.1.4 Note road number (in large cities)
1.1.5 Note landmark

1.2 Identify destination

1.2.1 Locate appropriate square on map and mark destination
1.2.2 Note part of town
1.2.3 Note address
1.2.4 Note road number (in large cities)
1.2.5 Note landmark

1.3 Find ways to reach destination

1.3.1 Obtain explicit directions to destination from reliable source
1.3.2 Study city street maps

1.3.2.1 Check back of map for indexes to local communities, streets,public and private buildings
1.3.2.2 Chart route from present location to destination

1.3.2.2.1 Note whether destination is North, South, East, or West
1.3.2.2.2 Identify thoroughfares that divide city in N-S and E-W
1.3.2.2.3 Note between which cross streets address is located
1.3.2.2.4 Note which streets are one-way and in which direction
1.3.2.2.5 Identify side streets parallel to main thoroughfares

1.4 Choose route that is most preferable

1.4.1 Consider length
1.4.2 Consider expected volume of traffic/congestion
1.4.3 Consider expected number of traffic lights
1.4.4 Consider one-way streets
1.4.5 Consider expected stress
1.4.6 Consider number of turns

1.5 Memorize (part of) route

1.5.1 Rehearsal

1.5.1.1 Rehearsal of street names
1.5.1.2 Rehearsal of directions
1.5.1.3 Rehearsal of landmarks
1.5.1.4 Rehearsal of road signs indicating part of town or road number

1.5.2 Verbal learning

1.5.2.1 Count number of turns, streets, or intersections
1.5.2.2 Mnemonics

1.5.2.2.1 Use mnemonics to remember street names
1.5.2.2.2 Use mnemonics to remember names of landmarks
1.5.2.2.3 Use mnemonics to remember sequence of directions
1.5.2.2.4 Use mnemonics to remember part of town or road number

1.5.2.3 Associate

1.5.2.3.1 Associate street names with prior knowledge
1.5.2.3.2 Associate names of landmarks with prior knowledge
1.5.2.3.3 Associate two or more street names from the map
1.5.2.3.4 Associate two or more names of landmarks from the map

1.5.3 Spatial learning

1.5.3.1 Visual imagery

1.5.3.1.1 Construct mental image of roads relative to each other
1.5.3.1.2 Construct mental image of position of landmarks relative to each other
1.5.3.1.3 Construct mental image of road network
1.5.3.1.4 Construct mental image of landmarks in network

1.5.3.2 Generate verbal cue for complex spatial configuration on map
1.5.3.3 Note specific shape of element, e.g. winding road
1.5.3.4 Note spatial relationship between two or three elements

2.0 Driving the fastest route from A to B in an unfamiliar city.

2.1 Check position

2.1.1 Check maps during stops to refresh memory
2.1.2 Maintain awareness of direction in which car is moving to effect correct turns when road signs lack info needed
2.1.3 Check road signs indicating part of town or road number
2.1.4 Glance at map or route card while driving and compare with street names on buildings etc.
2.1.5 Check landmarks marked on map

2.2 Anticipate key junctions

2.2.1 Estimate time remaining to next junction
2.2.2 Scan roadside for signs in advance of junction
2.2.3 Scan roadside for landmarks in advance of junction
2.2.4 Scan roadside for street names

2.3 Recover from disorientation

2.3.1 Look for first landmark to be seen and check map
2.3.2 Look for street name and check map
2.3.3 Go to first thoroughfare and drive in general direction of destination

2.3.4 Ask directions from passers-by (police, local resident)
2.3.5 Search for signs that lead to desired route
2.3.6 Return to last confirmed location

2.4 Recover from blocked roads

2.4.1 Go to first alternative road that leads in desired direction, and repeat this process until familiar signs are encountered
2.4.2 Go to first main road and follow in direction of destination
2.4.3 Stop and check map for shortest alternative route

2.5 Decide when destination has been reached

2.5.1 Check address
2.5.2 Check landmark
2.5.3 Check position

REPORT DOCUMENTATION PAGE

1. DEFENCE REPORT NUMBER (MOD-NL) TD 89-1057	2. RECIPIENT'S ACCESSION NUMBER	3. PERFORMING ORGANIZATION REPORT NUMBER IZF 1989-36
4. PROJECT/TASK/WORK UNIT NO. 733.1	5. CONTRACT NUMBER B89-36	6. REPORT DATE October 2, 1989
7. NUMBER OF PAGES 27	8. NUMBER OF REFERENCES 34	9. TYPE OF REPORT AND DATES COVERED Final

10. TITLE AND SUBTITLE

Navigation in unfamiliar cities: a review of the literature and a theoretical framework

11. AUTHOR(S)

J.M.C. Schraagen

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Institute for Perception
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

TNO Division of National Defence Research
Koningin Marialaan 21
2595 GA DEN HAAG

14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

This report is based on a literature review in which an attempt is made to identify those concepts and specific studies within cognitive science, that have direct relevance to navigation in unfamiliar cities. In particular, issues are discussed related to the strategies and representations used by drivers who have to find their way in unfamiliar cities. The interaction between the way spatial knowledge is represented and the search strategy used, is emphasized. A normative task analysis is proposed. The main goal of the report is to generate predictions to be tested in a subsequent field experiment.

16. DESCRIPTORS	IDENTIFIERS
Navigation Maps Spatial Orientation Artificial Intelligence Driving Problem solving	Cognitive Science Spatial Knowledge

17a. SECURITY CLASSIFICATION (OF REPORT) -	17b. SECURITY CLASSIFICATION (OF PAGE) -	17c. SECURITY CLASSIFICATION (OF ABSTRACT) -

18. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited availability	17d. SECURITY CLASSIFICATION (OF TITLES) -

VERZENDLIJST

1. Hoofddirecteur van de Hoofdgroep Defensieonderzoek TNO

2. Directie Wetenschappelijk Onderzoek en Ontwikkeling Defensie

3. { Hoofd Wetenschappelijk Onderzoek KL
Plv. Hoofd Wetenschappelijk Onderzoek KL

4,5. Hoofd Wetenschappelijk Onderzoek KLu

6. { Hoofd Wetenschappelijk Onderzoek KM
Plv. Hoofd Wetenschappelijk Onderzoek KM

7. Wnd. Directeur Militair Geneeskundige Diensten
Cdre vliegerarts H.H.M. van den Biggelaar

8. Inspecteur Geneeskundige Dienst KL
Brig.Gen.-arts B.C. Mels

9. Inspecteur Geneeskundige Dienst KLu
Cdre J.Th. Versteeg

10. Inspecteur Geneeskundige Dienst Zeemacht
Cdr-arts A.J. Noordhoek

11, 12, 13. Hoofd van het Wetensch. en Techn. Doc.- en Inform.
Centrum voor de Krijgsmacht

LEDEN WAARNEMINGS CONTACT COMMISSIE

14. Maj.Ir. W.C.M. Bouwmans
15. LTZAR1 F.D.J.R. Feunekes
16. Dr. N. Guns
17. Drs. C.W. Lamberts
18. Ir. P.H. van Overbeek
19. Drs. W. Pelt
20. Maj. dierenarts H.W. Poen
21. Drs. F.H.J.I. Rameckers
22. LTZSD2OC KV Drs. M.B.A.M. Scheffers
23. Prof.Ir. C. van Schooneveld
24. LKol.Drs. H.W. de Swart
25. Kol. vliegerarts B. Voorsluijs

Extra exemplaren van dit rapport kunnen worden aangevraagd door tussenkomst van de HWOs of de DWOO.
