Technical Report 756

A Comparison of Terrain Association and Resection as Methods of Position Location

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U. S. Army

Research Institute for the Behavioral and Social Sciences

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This research examined two methods of position fixing, terrain association and resection to determine which would result in faster and more accurate judgments of location. The research was conducted in the Surface Navigation and Orientation Trainer (SURNOT), which projects slide images a full 360 degree field of view. Two groups of soldiers (n = 12 each) were shown terrain scenes, given a 1:50,000 topographic map of the area, and located their position by terrain association and resection. Overall, performance was poor: There was
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20. Abstract (Continued)

no significant difference in accuracy of solution between the two groups (723 meters average error), but terrain association was approximately 3 minutes faster. The results were interpreted in terms of a two-stage position fixing model, and suggest that errors in position fixing occur early in the process.

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Land Navigation Training

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FOREWORD

The U.S. Army Research Institute's Fort Benning Field Unit has been tasked to perform research leading to improved land navigation performance. There are many skills required for minimal proficiency in land navigation. Foremost of these is the ability to position locate, or accurately determine one's location given only the surrounding terrain and a map of the area. Without this skill, a soldier cannot adequately confirm arrival at a destination, or ensure that a particular route is being followed.

The following report describes an experiment that examined the speed and accuracy of two methods of position locating--terrain association and resection. Parts of this work have been presented to researchers representing the Army Science Board, as well as to the Commander and staff of the 29th Infantry Regiment. The results have had an impact upon the newly developed program of instruction for One Station Unit Training, and have demonstrated the need for more training and instruction in the fundamentals of terrain association. This work constitutes part of the Army Research Institute's research on Land Navigation Training, and was carried out in support of the U.S. Army Infantry Center at Fort Benning.

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A COMPARISON OF TERRAIN ASSOCIATION AND RESECTION AS METHODS OF POSITION LOCATION

EXECUTIVE SUMMARY

Requirement:

The focus of this research was to determine performance differences in the speed and accuracy of position locating as a function of method used, either terrain association or resection. Specifically, we were interested in the method that would result in faster and/or more accurate estimates of location.

Procedure:

The research was conducted in the Surface Navigation and Orientation Trainer, which projects slide images a full 360 degrees on a horizontal plane. Two groups of soldiers (n = 12 each group) were shown a terrain scene, given a map of the area, and were told to locate their position by using either terrain association or resection.

Findings:

1. Soldiers performing terrain association solved the problems approximately 3 minutes faster than soldiers performing resections.

2. There were no group differences in accuracy of solution between the two groups, nor were there differences in soldiers' estimates of how accurate their solutions were.

Utilization of Findings:

The results suggest that in time-critical situations soldiers should use terrain association to position locate: The additional accuracy obtained by resection did not justify the additional time. Furthermore, the task, conditions, and standards for position-fixing methods should be reexamined in light of the present findings: approximately 700 meters error with an average solution time of 10.2 minutes. These figures compare to standards of less than 100 meters error in less than 7.0 minutes solution time.

A COMPARISON OF TERRAIN ASSOCIATION AND RESECTION AS METHODS OF POSITION LOCATION

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A COMPARISON OF TERRAIN ASSOCIATION AND RESECTION AS METHODS OF POSITION LOCATION

INTRODUCTION

A fundamental skill of land navigation is the ability to locate one's position on a map given only the surrounding terrain and, perhaps, a cardinal direction (Findlay, Roach, & Cogan, 1957). This skill is referred to as position locating, and it is perhaps one of the most important land navigation skills: Without this ability soldiers are incapable of establishing their whereabouts. Thus, it follows that they cannot report enemy locations or communicate other vital battlefield location information. The purpose of this report is to describe the results of an experiment contrasting two methods of position locating, terrain association and resection, to determine which of the two methods results in faster and/or more accurate judgments of one's location. The emphasis on examining speed and accuracy in this research corresponds to the vital characteristics of position location needed in combat--soldiers must be capable of identifying their position quickly and with a minimum of error.

Methods of Position Location

There are four common methods of position locating: resection, modified resection, single feature resection, and terrain association. The first three of these are based on (or derived from) principles of triangulation and are quantitative in nature, while the last is, overtly, a qualitative process.

Resection. In performing a resection at least two terrain features must be identified along with their corresponding representations on the map. Azimuths to the terrain features are determined and their back azimuths are calculated. Back azimuths are determined by a simple rule: If the azimuth to a feature is less than 180 degrees, add 180; if the azimuth is greater than 180, subtract 180 degrees. Following this, the back azimuths are drawn on the map from the features. For a two feature resection the point of intersection of the back azimuths fixes the general location of the position. For a three feature resection a triangle results, and its center of mass is taken as the solution.

Modified Resection. Modified resection is similar to resection only there is no access to a compass and precise azimuths cannot be determined. Instead, the map is oriented to the terrain, and a straightedge is lined up from the map feature to the terrain feature. A line is drawn and the procedure is repeated for (at least) a second pair of terrain/map features. Again, the point of intersection of two lines or the triangle formed by three azimuths locates the position.

Single Feature Resection. In a single feature resection only one pair of terrain/map features is used. After an azimuth to a terrain feature has been determined and a line (e.g., back azimuth) is drawn on the map, distance to the terrain feature is estimated. This distance is then marked off on the map line from the terrain feature.

Terrain Association. This method of position location is qualitative in nature in that the position is located based on map/terrain relations exclusively. Little is known about the underlying cognitive processes involved in terrain association (Milligan & Waldkoetter, 1979), but some generalities can be stated. First, distance estimation skills are required. At a minimum the ability to estimate relative distances to multiple landmarks (e.g., the mineshaft is further away than the lake) is needed to place one's self in multidimensional space (Shepard, 1962a, 1962b). Hence, the need to judge absolute distances is probably not as important for terrain association as it is for single feature resection. A second important process appears to be the construction of a "mental model" of the terrain (Cross, Rugge, & Thorndyke, 1982). The contents of the mental model have not been well specified at this time. However, we can speculate that the model consists of features which, ideally, will allow one to dismiss many of the competing candidate areas from consideration. Finally, the mental model is continuously updated and refined as more terrain features are interrogated.

A Procedural Model of Position Location

Recently Cross, Rugge, & Thorndyke (1982) outlined a procedure-based process model of position locating. The model was fashioned after the results of a comprehensive experiment in which verbal protocols, tape recorded during the position location process, were obtained from novice and expert navigators. The following is a brief description of that model.

The protocols suggested that position locating proceeded in two stages. The processes of the two stages are independent, but the second stage is dependent upon the information output from the first. In Stage 1, which we will refer to as global fixing, the goal is to identify the smallest area of uncertainty concerning one's potential location. According to Cross et al., the first step is to orient the map with the terrain. Next, one attempts to locate a terrain feature which can be identified on the map, or alternatively, locate a map feature which can be identified on the map. Cross et al. refer to the class of features used during the global fix as "macro referents." Through judicious use of macro referents, the size of the area of uncertainty can be substantially reduced. Alternatively, if a single area cannot be identified or reduced to a manageable size the global fixing procedure starts over. When a single area of uncertainty is reduced to a satisfactory one, the second phase begins.

During Stage 2 (local fixing, our term), new referents are selected (micro referents), and the processes from the global fixing stage are repeated but on a smaller scale. Cross et al. postulate that an internal counter is incremented each time that a terrain/map feature match is found, and that new micro referents are selected and matched in an attempt to confirm or disconfirm one's precise position. A solution is reached and the process terminates when the number of feature matches exceeds some internal criterion.

Although resection contains a quantitative component (during the local fixing procedure), there is still a great deal of terrain association occurring. Specifically, all of the global fixing process, during which the size of the area of uncertainty is reduced, can be accomplished only through terrain association. Hence, the major difference between the two classes of position locating procedures can be reduced to differences in the second stage or local fixing process.

RATIONALE FOR THE CURRENT RESEARCH

The purpose of the present research was to examine several performance measures associated with position locating. First, which of two procedures, if either, would result in more accurate position location estimates? Our hypothesis was that resection would lead to more accurate solutions given the analytic second stage. Second, would one method take substantially more time to complete than the other? We had no firm hypotheses concerning this point. It seemed reasonable that the mechanical aspects of resection (determining azimuths to features) might increase times to solve problems. On the other hand, since the same features can be used for both the global and local fixing stages, resection might be faster.

Third, we wanted to assess how accurate soldiers thought their solutions were. To examine this we had the soldiers estimate how close to the actual location they thought their solutions were. Again, we felt that the analytic component of resection might lead to higher accuracy estimates for soldiers doing the resection problems. Finally, we had subjects tell us what features they used during the task, and to rank order the problems in terms of difficulty. We expected that soldiers using terrain association would use more features than those doing resection, given that a resection can be performed with only two features. Ratings of problem difficulty were collected to determine if objective performance measures were related in any fashion to the perceived difficulty of each problem.

Method

Subjects. Subjects were 24 soldiers waiting to attend the Infantry Officer Basic Course at Fort Benning, Georgia. Commissioning sources included Officer Candidate School and Reserve Officer Training Course. Soldiers were tested individually.

Apparatus. The experiment was run in the Surface Navigation and Orientation Trainer (SURNOT). Attributes of SURNOT have been described in detail elsewhere (Andrews, 1979). Briefly, the SURNOT system projects slides (10.6 X 12.70 centimeter format) a full 360-degree field of view. The interior of the circular device is approximately 7.62 meters in diameter, and its concave screen walls are 3.35 meters high. In the projected image nearly all perceptual relationships are veridical with the actual terrain except for a slight vertical compression at the extreme top of the image. The construction of, and purpose of SURNOT (slide projection) necessitates that slides be shown in a dark room. When a slide is being shown, however, there is enough light in SURNOT to read without any problem. With these general characteristics SURNOT gives the impression of being at the actual outdoor location.

Materials. One practice slide and three experimental slides were used during the task. The practice slide was a desert scene from southern California. Two of the experimental slides were of mountainous desert terrain from southern California. One slide pictured Bell Mountain, from the Apple Valley area (referred to as BM), and the other was taken near the city of Warren, California (WN).

The third experimental slide was taken in the north Georgia hills, near the town of Mount Pleasant (MP). Copies of the actual map portions used, along with descriptive information about each location, are included in the Appendix.

Soldiers were given materials as consistent as possible with the conditions outlined in the Soldier's Manual of Common Tasks (SMCT, 1985) for determining a location on the ground by terrain association (Task No. 071-329-1005), and from the Soldier's Manual 11B (1985, skill levels 2 - 4), locate an unknown point on a map or on the ground by resection (Task No. 071-329-1015). Soldiers in both tasks were provided with a protractor (GTA 5-2-12, 1981), a china marker, a lighted 2X magnifying glass (used if needed), and a table on which to work. For each slide, soldiers were given a cutout portion (8.5 X 11 inches) of a 1:50,000 topographic map which was enclosed in a clear document protector. One major difference between the experiment and the conditions as outlined in the SMCT was that in the experiment a 4 X 4 grid square was outlined. Soldiers were told that their location would be within the outlined area although visible terrain would not always be within the area. Soldiers doing the resection problems were also given access to a large mock-up of a lensatic compass. The compass was situated chest high on a tripod in the middle of SURNOT. Azimuths from this compass were estimated to be accurate to within plus or minus 3 degrees which is the tolerance allowed for lensatic compasses.

Experimental Design. The experimental design included three factors: task, a between-subjects variable with two levels (terrain association and resection, n = 12 soldiers each); problem order (first, second, or third), a within-subjects variable; and slide (BM, WN, and MP), also a within-subjects variable. The factors of problem order and slide were not crossed within subjects within tasks. That is, each soldier did not experience each slide at each level of difficulty. Because of this, performance measures on these variables were analyzed separately. Measures on five dependent variables were collected: time to solution (TTS) for each slide; actual error of the position location; estimated error of the position location; rated difficulty of the slide; and, the number of features used for each slide.

Procedure. Soldiers were scheduled for the experiment in their company area. They were assigned to either the terrain association or the resection task based on order of appearance at the test site. They were given a short description of SURNOT, shown a sample slide, and given a map corresponding to the area depicted by the slide. After this brief introduction they were told that their task would be to locate their position as accurately as possible.

Soldiers in the terrain association task were told to use techniques that they had learned in their land navigation courses to accurately fix their positions. Subjects doing the resections were told to use those procedures, as they had learned in their land navigation courses to accurately fix their positions. All soldiers were asked to describe the particular procedures they were to follow and all were able to. However, data from two subjects in the resection condition were replaced since it was clear that they were unable to perform the task (e.g., one soldier determined azimuths to trees and cactus plants).

Following this, all soldiers were shown the materials available for their use. They were instructed to look at the practice slide and refresh their terrain association and/or resection skills. Four to five minutes were given for this review before the task began.

Prior to the actual task, soldiers were told that there would be no grid-magnetic north conversions (g-m angle), and that they would be told where north was for each slide. Slides were presented in a counterbalanced order across soldiers. When a soldier located his position he was instructed to mark the map overlay and inform the experimenter that he was done. Following this, the soldier was asked what terrain features he used during the slide and to estimate how accurate he thought his solution was. The next problem was given and the task continued. After the final slide soldiers were asked which of the three problems was the easiest (or hardest) and then which was the hardest (or easiest). Order of the questions (easiest, hardest) was counterbalanced across soldiers. The remaining problem was considered medium difficulty. The order of difficulty was then read back to the soldier to ensure its correctness.

RESULTS

Features Used

The feature reports can be taken as a minimum index of the quantity and quality of features used during the task. They provide a minimum count of the features that were used in that some minor features which were actually used may not have been reported or remembered (Ericsson & Simon, 1984). In addition, the reports are limited in that particular relations among features, such as configural properties (Dulany, Carlson, & Dewey, 1984; Lasky & Kallio, 1978), are difficult, if not impossible to verbalize. For example, soldiers may have reported two features but not mentioned that the particular spatial relationship between the features was also of importance. Notwithstanding, the feature reports are of importance in contrasting performance across the two tasks. For purposes of this analysis, problem order was not included as a factor.

Inspection of the feature reports showed no great differences between the groups in terms of what features were selected: Reports from soldiers doing terrain association were more general in nature, often referring to a mountain range, whereas soldiers in the resection task would refer to a particular point on the range. This finding mirrors the general task demands--terrain association does not necessarily require the use of specific points as does resection. However, soldiers doing terrain association reported using more features, averaging 3.19 features on each of the problems. On resection problems, soldiers reported using an average of 2.25 features. This difference was reliable ($F(1,22) = 22.5$, $MSe = 2.14$, $p < .01$). Note that the number of features reported by soldiers performing the resections was only just above the minimum (two) required for this task.

Difficulty Ratings

The particular slides were selected, on the basis of a pilot study, to reflect a range of perceived difficulty. Although the pilot research resulted in a consistent ordering of difficulty of position locating (specifically, BM, WN, and MP, from easiest to hardest), individual differences were found during the actual experiment. Table 1 shows the average difficulty ratings as a function of task for each of the three slides. For this analysis, slides rated "easy" were assigned a value of 1, "medium," 2, and "hard," 3. The rank orders for each slide were then averaged across soldiers.

In spite of the individual differences, the average difficulty rating across pictures lined up as in the pilot study. Specifically, BM was rated the easiest, MP the hardest, and WN in the middle. A single factor analysis of variance (ANOVA) on the ratings for each slide confirmed the differences in rated difficulty across the slides ($\underline{F}(2,22) = 12.4$, $MSe = .24$, $\underline{p} < .01$). Post tests revealed that all three slides differed with respect to rated difficulty ($\underline{p}$'s $< .05$, Newman-Keuls). There was no interaction of task with slide, hence, the perceived difficulty of each slide did not differ across the two tasks.

Table 1

Average Difficulty Ratings as a Function of Task and Slide

	Slide		
Task	BM	WN	MP
Terrain Association	1.33	2.08	2.58
Resection	1.67	1.92	2.42

Time to Solution (TTS)

Overall, soldiers in the two tasks differed in how long they took to solve the problems. Soldiers in the terrain association condition averaged 526 seconds per problem, while those in the resection condition averaged 707 seconds. This difference was reliable ($\underline{F}(1,12) = 8.6$, $MSe = 68868$, $\underline{p} < .012$), and seems best explained by the extra time needed for the mechanical aspects of the resection task.

Problem Order. Table 2 shows the average TTS as a function of task (terrain association versus resection) and problem order (either first, second, or third). The most notable trend is that solution times differ initially between tasks, but tend to converge by the third problem. A two factor ANOVA (task by problem order) confirmed the interaction of the two variables ($\underline{F}(2,44) = 4.5$, $MSe = 66919$, $\underline{p} < .02$). Post-hoc tests (Newman-Keuls) showed that resection took longer than terrain association on the first and second problems ($\underline{p}$'s $< .05$).

Slide. TTS for the various slides was also examined (Table 3). The major question was, do solution times line up as one would expect given the difficulty ratings? Table 3 shows average TTS for each of the three slides as a function of task. In general, TTS increases across the three slides for both conditions, and the increases associated with each of the slides is fairly consistent, ranging from 136 to 225 seconds. In addition, if we collapse across tasks the increases in TTS mirror the difficulty ratings for the slides.

A two factor ANOVA (task by slide) revealed a significant effect of task (as was found with Problem, above), as well as reliable differences in TTS across the slides ($F(2,44 = 7.1$, MSe = 60792, $p < .002$). Post tests showed that BM was solved reliably faster than the other two slides ($p < .01$).

Time to Solution - Summary

Two results of interest emerged with respect to TTS. First, the resection problems took longer to solve initially, but were not significantly longer by the third problem. This suggests that soldiers doing the resection problems learned, as measured by this index. However, the most likely explanation of what was learned is that they became more familiar with the mechanics of performing the resections (e.g., moving the compass, calculating back azimuths, etc.). Second, TTS was generally related to the rated difficulty of the problems.

Table 2

Average Time to Solution (Seconds) as a Function of Task and Problem Order

	Problem Order		
Task	1	2	3
Terrain Association	442	507	631
Resection	813	745	546

Table 3

Average Time to Solution (Seconds) as a Function of Task and Slide

	Slide		
Task	BM	WN	MP
Terrain Association	382	527	670
Resection	564	752	806

Accuracy of Solution

In general the position locations were not accurate. Soldiers in the terrain association condition averaged 764 meters from the actual location while soldiers in the resection condition missed the mark by 682 meters. Although this difference was fairly large (82 meters), it was not reliable ($p > .10$) given the large within-group variance.

Problem Order. Table 4 shows average actual error as a function of task and problem order. Actual error was fairly consistent across the three problems for soldiers in the resection condition suggesting that little learning occurred. However, soldiers doing terrain association performed poorly on the second problem. Inspection of the data showed that there was one individual who had an error in excess of 2900 meters on his second problem. If this data point is taken out, the average error is reduced to approximately 760 meters, clearly in line with performance on the first and last problems. With this in mind, there appear to be no noteworthy trends as a function of problem order. More important, however, is the noticeable lack of learning as indexed by this measure. We might expect a decrease in actual error with subsequent problems. A two factor ANOVA (task by order) confirmed the lack of effects of problem order, and this variable did not interact with task (p's $> .10$). Although soldiers were learning the mechanics of the task (as indexed by TTS), the accuracy of their fixes did not increase.

Slide. Table 5 shows the actual error on each slide as a function of task. Performance across the slides varied, with WN appearing the most difficult. In addition WN seems to have been more difficult for soldiers doing the terrain association task than for those doing the resection. A two factor ANOVA (task by slide) confirmed differences in difficulty of the slides ($F(2,44) = 6.9$, $MSe = 377556$, $p = .002$), but the interaction was not reliable. Posttest showed that BM resulted in the most accurate solutions ($p < .01$).

Table 4

Average Actual Error (Meters) as a Function of Task and Problem Order

	Problem Order		
Task	1	2	3
Terrain Association	608	938	745
Resection	673	647	727

Accuracy of Solution - Summary

In light of the results for TTS, the accuracy data are surprising. There were no differences in accuracy attributable to problem order, but the different slides produced various levels of accuracy. More interesting, however, is that rated difficulty did not reflect actual error (note the WN - WP performance reversal from rated difficulty to actual error). This suggests (1) soldiers did not consider how accurate they were in their difficulty ratings, or (2)

Table 5

Average Actual Error (Meters) as a Function of Task and Slide

Task	Slide BM	WN	MP
Terrain Association	306	1167	767
Resection	413	857	777

soldiers had little idea of how accurate their solutions were. We will now turn to soldiers' estimates of accuracy which may shed light on this issue.

Estimated Error

Estimated error can be interpreted in two ways. One, we can take the measure at face value and use it as a reflection of how well soldiers could determine their performance. In a second sense, the measure can be seen as reflecting confidence in the solution. In fact, we found this measure preferable to an explicit confidence question--pilot research revealed that soldiers were always extremely confident of their solutions (see Schendel, Morey, Granier, & Hall, 1983 for similar findings).

Taken as an index how accurate soldiers thought their solutions were, we can conclude that they had little appreciation for the difficulty of the task. On the average, terrain association soldiers estimated their position locations to be within 374 meters (compared to 764 meters actual error) of the actual location; resection soldiers within 312 meters (versus 682 meters). This small difference between tasks was not significant ($p > .10$).

Problem Order. Table 6 shows estimated error as a function of task and problem order. Error estimates varied little for soldiers doing the resection problems while the estimates of error increased across problems for soldiers doing terrain association. This interaction, however, was not reliable ($p > .10$). Thus, if we take the measure as a confdence index, soldier's confidence remained stable throughout the series of problems.

Slide. Table 7 shows estimated error as a function of task and slide. Soldiers were most certain of their solution on the BM slide, but the magnitude of estimated error differed on the other two slides as a function of which task the soldier was in. A two factor ANOVA confirmed the differences in estimates across the slides ($F(2,44) = 3.2$, $MSe = 135239$, $p < .048$). The two factors, however, did not interact ($F = 1.5$). Posttests showed that BM resulted in the lowest estimated errors ($p < .05$).

Table 6

Average Estimated Error (Meters) as a Function of Task and Problem Order

Task	Problem Order 1	2	3
Terrain Association	273	350	500
Resection	317	303	319

Table 7

Average Estimated Error (Meters) as a Function of Task and Slide

Task	Slide BM	WN	MP
Terrain Association	242	496	385
Resection	146	269	522

Relations Among Variables

Actual Versus Estimated Error. Figures 1a and 1b are scatterplots of actual versus estimated error, averaged across the three problems for each subject in the terrain association and resection conditions, respectively. For terrain association there was a tendency for error estimates to increase with actual error. However, this relationship was weak and not reliable ($r = +.306$, $p > .10$). For resection (Figure 1b), it looks as though the relationship was reversed--larger estimates of error resulted in smaller actual error. Again, the relationship was weak ($r = .230$, $p > .10$). From these figures, it is clear that not only were soldiers unable to predict with any accuracy their actual error, but their estimates were not linearly related to actual error. It seemed reasonable, however, that error estimates may have been monotonically related to actual performance. To examine this, Spearman rank-order correlations were calculated. The correlations still remained low ($r = +.234$, terrain association; $r = +.007$, resection). On the basis of these analyses, there appears to be no immediate nor obvious relationship between actual and estimated error, suggesting that soldiers had little knowledge of their performance on the task.

Figure 1a. Scatterplot of actual versus estimated error for soldiers performing terrain association.

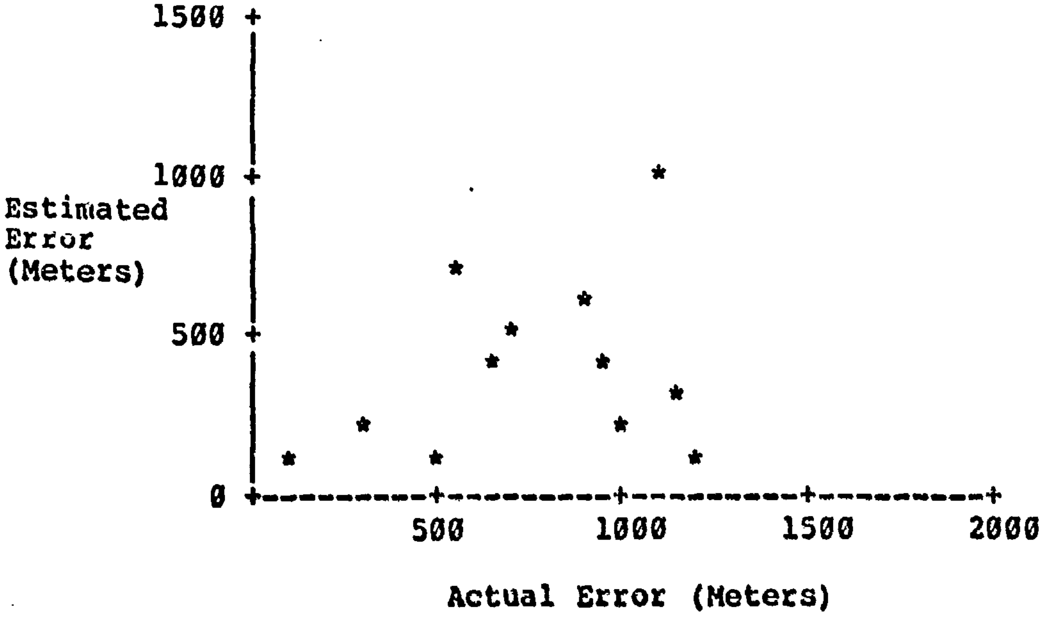
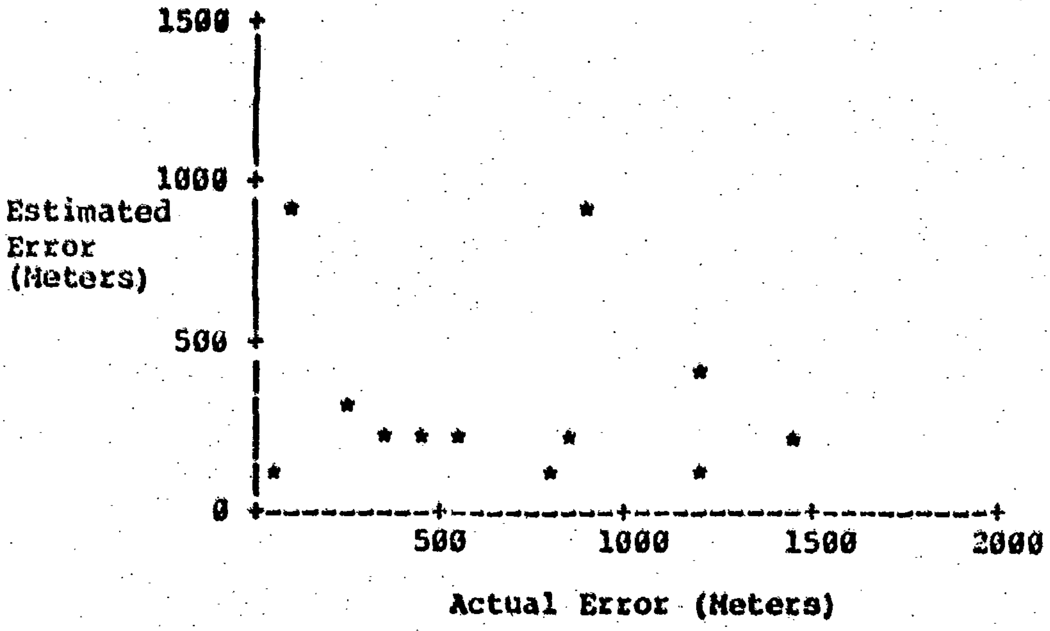


Figure 1b. Scatterplot of actual versus estimated error for soldiers performing resection.



Time to Solution Versus Actual Error. Figures 2a and 2b are scatterplots of time to solution versus actual error on the terrain association and resection tasks, respectively. For terrain association, there was a moderate relationship between the two variables. Actual error decreased with increases in time to solve the problems. The relation proved to be reliable ($r = -.587$, $t(10) = 2.29$, $p < .03$). The same cannot be said for resection, however (Figure 2b). The relationship appears weak, and its direction is not clear from the plot. The correlation was positive and not significant ($r = +.128$, $p > .10$). In general, time appears not to be a factor related to accuracy of solution of resection problems.

Time to Solution Versus Estimated Error. Figures 3a and 3b show the scatterplots of these variables for each of the tasks. There is no clear relationship between time to solution and estimated error for terrain association ($r = .081$, $p > .10$). For the resection group, the relationship was stronger ($r = +.490$) and in the opposite direction. That is, longer solution times were associated with larger estimates of error. Still, the relationship was only marginally significant ($.05 < p < .10$).

Relations Among Variables - Summary

In general, interrelationships among the variables were weak. In only one instance was there a substantial relationship--time to solution and accuracy correlated highly for performance on the terrain association task ($r = -.587$). More important, however, was the finding that estimated error was not related to actual error, suggesting that soldiers had little idea concerning the accuracy of their fixes.

DISCUSSION

Two major results emerged from this research. One was that a method of position location which incorporates quantitative, algorithmic procedures into the process (resection) resulted in fixes which were no better than those resulting from a qualitative process (terrain association). The second major finding was that soldiers had virtually no idea of how accurate their position fixes were, independent of the particular procedure. This was substantiated by the low rank-order correlations between actual and estimated error.

Three secondary results are also worth noting. One is that soldiers doing the resection task used about the minimum number of features needed to perform the task (2). Although this is an expedient method, one should attempt to confirm or disconfirm the intersection of two azimuths by plotting a third. A second result was that there were individual differences pertaining to rated difficulty of the slides. If we use actual error as a measure of difficulty, the Cross et al. obtained similar findings (see their Table 1, p. 20). This argues against establishing any general index of difficulty and suggests that we must explore the subjective aspects of the position location procedure (e.g., composition of the mental models) to determine which features are included. Finally, if we examine the two tasks in terms of costs and benefits, there was little additional benefit realized with the precision of the resection task. More important, there was a cost of an additional 3 minutes in solution times as compared to terrain association.

Figure 2a. Scatterplot of time to solution versus actual error for soldiers performing terrain association.

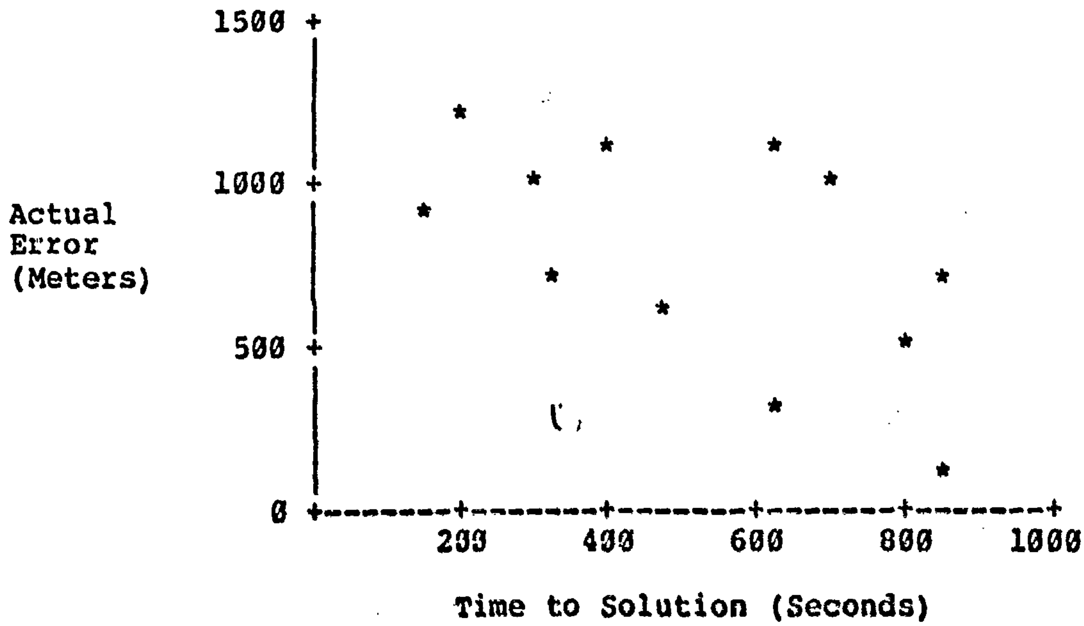


Figure 2b. Scatterplot of time to solution versus actual error for soldiers performing resection.

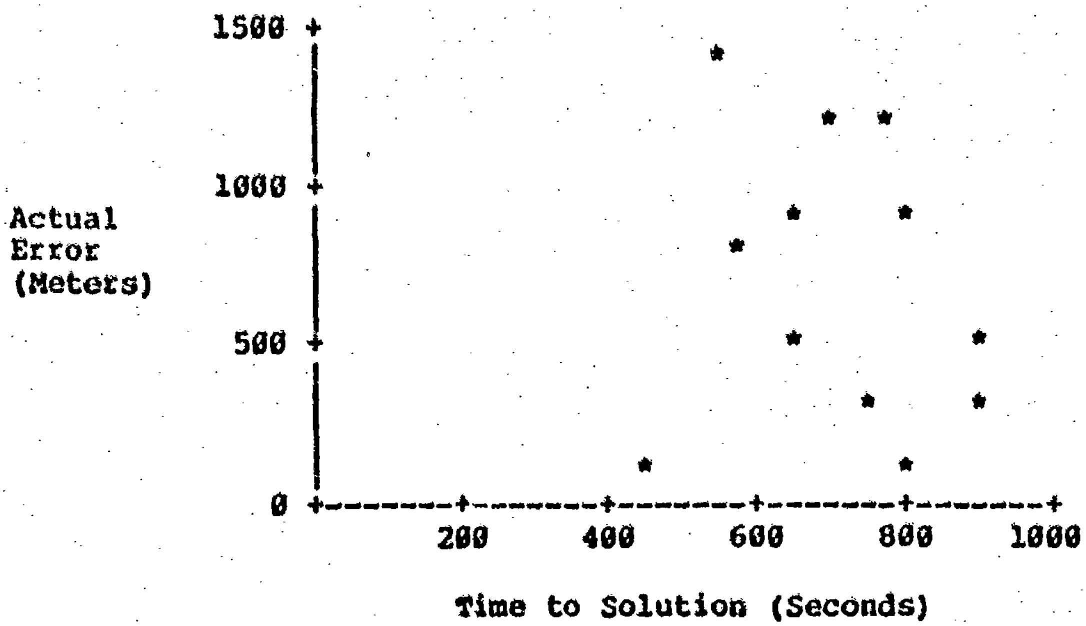


Figure 3a. Scatterplot of time to solution versus estimated error for soldiers performing terrain association.

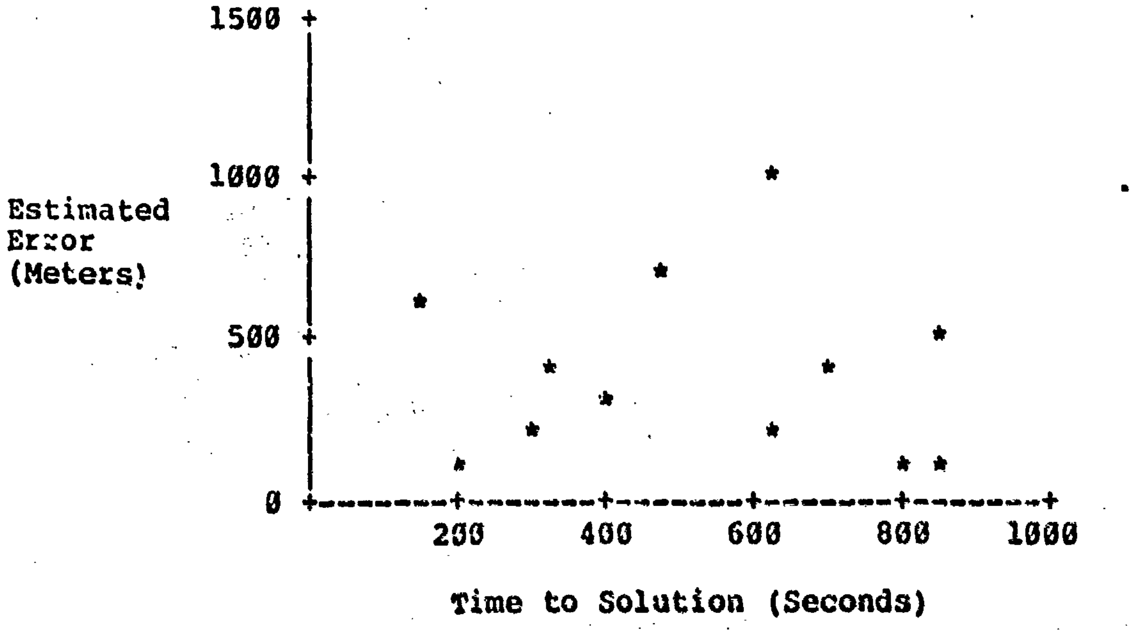
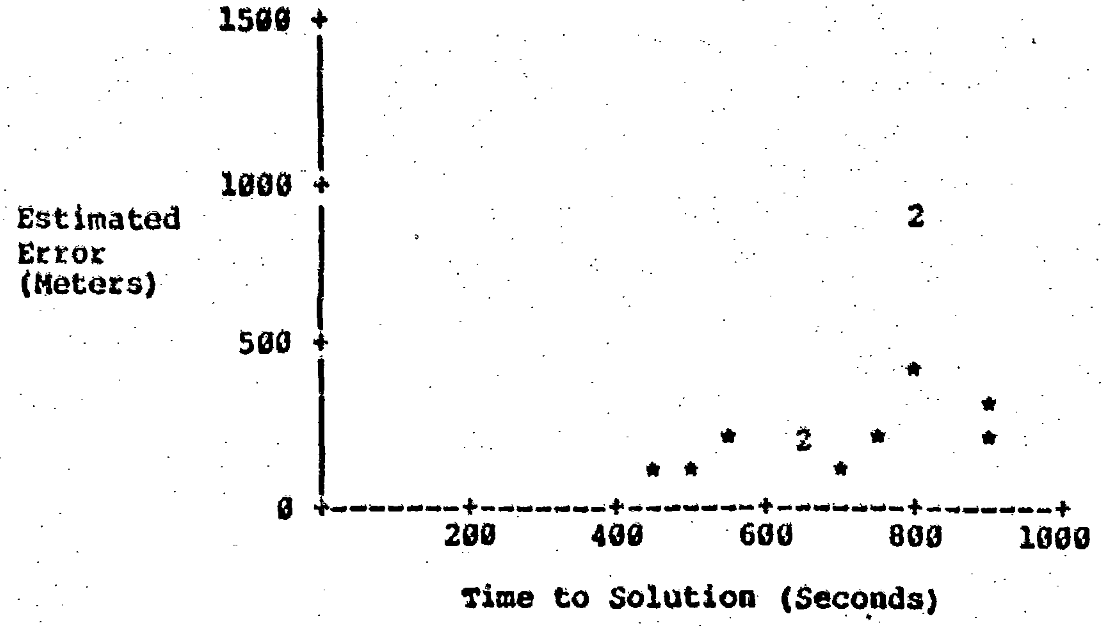


Figure 3b. Scatterplot of time to solution versus estimated error for soldiers performing resection.



Terrain Association and Resection Revisited

We are still left with the question of why performance on a procedure with an analytic component was no better than performance on a procedure which was qualitative throughout. The lack of differences in actual error strongly suggests that performance was largely determined during the global fixing procedure. That is, soldiers doing the resections may have attempted to start the local fixing procedure before the global fixing was complete. This could have resulted in an area of uncertainty which was not sufficiently small, or in more than one area of uncertainty. We would suggest that both of these problems arise from an incomplete or inadequate mental model of the terrain. The model was neither rich nor developed enough to permit local fixing to begin.

Relations to Standards

The present data can easily be compared to current U.S. Army standards for these tasks (Soldier's Manual of Common Tasks, 1985). For position location by terrain association, the standard requires accuracy within 100 meters in less than 7 minutes. Clearly, the overall performance of the majority of soldiers, independent of condition, was substandard along both dimensions (accuracy and time). However, the results also suggest that the standards are difficult to meet: In only three cases out of 72 did soldiers meet both time and distance standard on at least one problem; no soldier met standard on more than one problem. Further examination showed that the time standard (a solution in less than 7 minutes) was a little easier to meet than was the distance standard. Overall, the time standard was met 30.6% of the time, while the distance standard (no more than 100 meters error) was met only 26.4% of the time. At any rate, room for improvement does exist, and soldiers clearly need more exposure to position location problems in an effort to improve their skills.

Other Issues

We feel that the performance exhibited on this task is probably an underestimate of what true performance would be in the field. While SURNOT is a remarkable simulation of the natural environment, it limits the navigator in several ways. One, the navigator cannot gain additional information about the terrain by moving around. Clearly, slight movements in the field could easily resolve questions a navigator might have (e.g., does the land drop off over there?). Two, there was an effort to minimize the inclusion of subtle direction cues, such as sun location, in SURNOT pictures. Hence, soldiers had no access to this type of information.

In any event, however, we feel that these drawbacks do not seriously undermine the experiment described above. Only the measures of error should be affected by these constraints anyway.

SUMMARY

The ability of soldiers to position locate using either terrain association or resection was examined in the SURNOT device. They were shown three slides of varying terrain from across the country and given a 1:50,000 map of the corresponding area with a 4 X 4 grid-square area marked off. One group of subjects determined their location by using terrain association; a second group determined their location by using resection. Time to arrive at a solution and distance from the true location were measured. Results showed that soldiers averaged about 750 meters error and took approximately 12.5 minutes to position locate.

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APPENDIX

Mapsheets Used

Figures A1, A2, and A3 are reduced size, black and white copies of the mapsheet cutouts given to soldiers during the task. During the actual experiment, colored 8.5 X 11 inch cutouts were used. The solution for each slide is denoted by an "X" on each map. Additional information concerning each mapsheet is as follows:

(1) Bell Mountain (BM):

Map Name	:	Apple Valley, CA
Sheet Number	:	2553 II
Contour Interval	:	40 feet
Scale	:	1:50,000
Solution	:	862283

(2) Warren (WN):

Map Name	:	Mojave, CA
Sheet Number	:	2354 II
Contour Interval	:	100 feet
Scale	:	1:50,000
Solution	:	902862

(3) Mount Pleasant (MP):

Map Name	:	Suches, GA
Sheet Number	:	4135 II
Contour Interval	:	40 feet
Scale	:	1:50,000
Solution	:	689449

Figure A1. Bell Mountain location used for the BM slide.

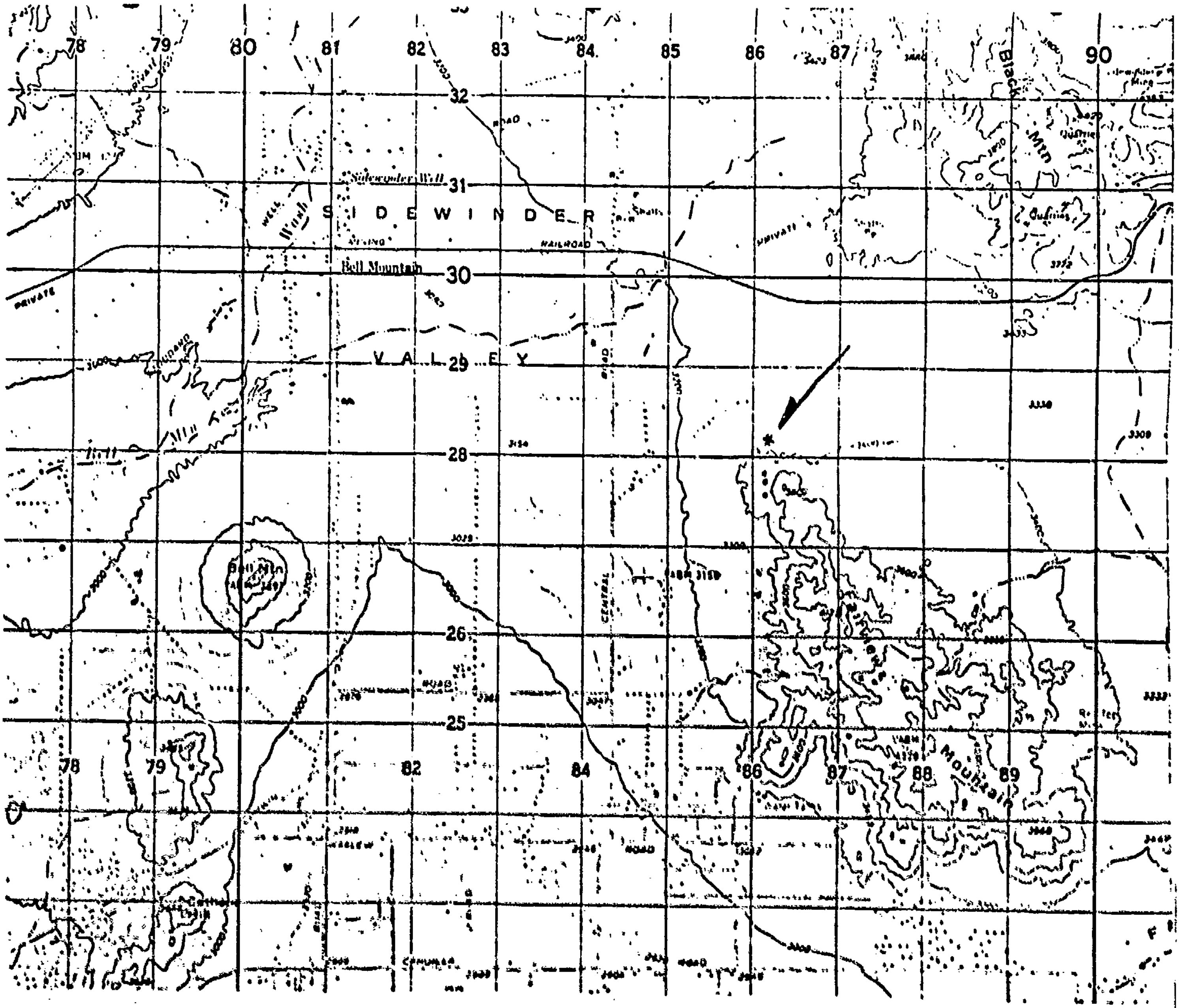

Figure A2. Warren location used for the WN slide.

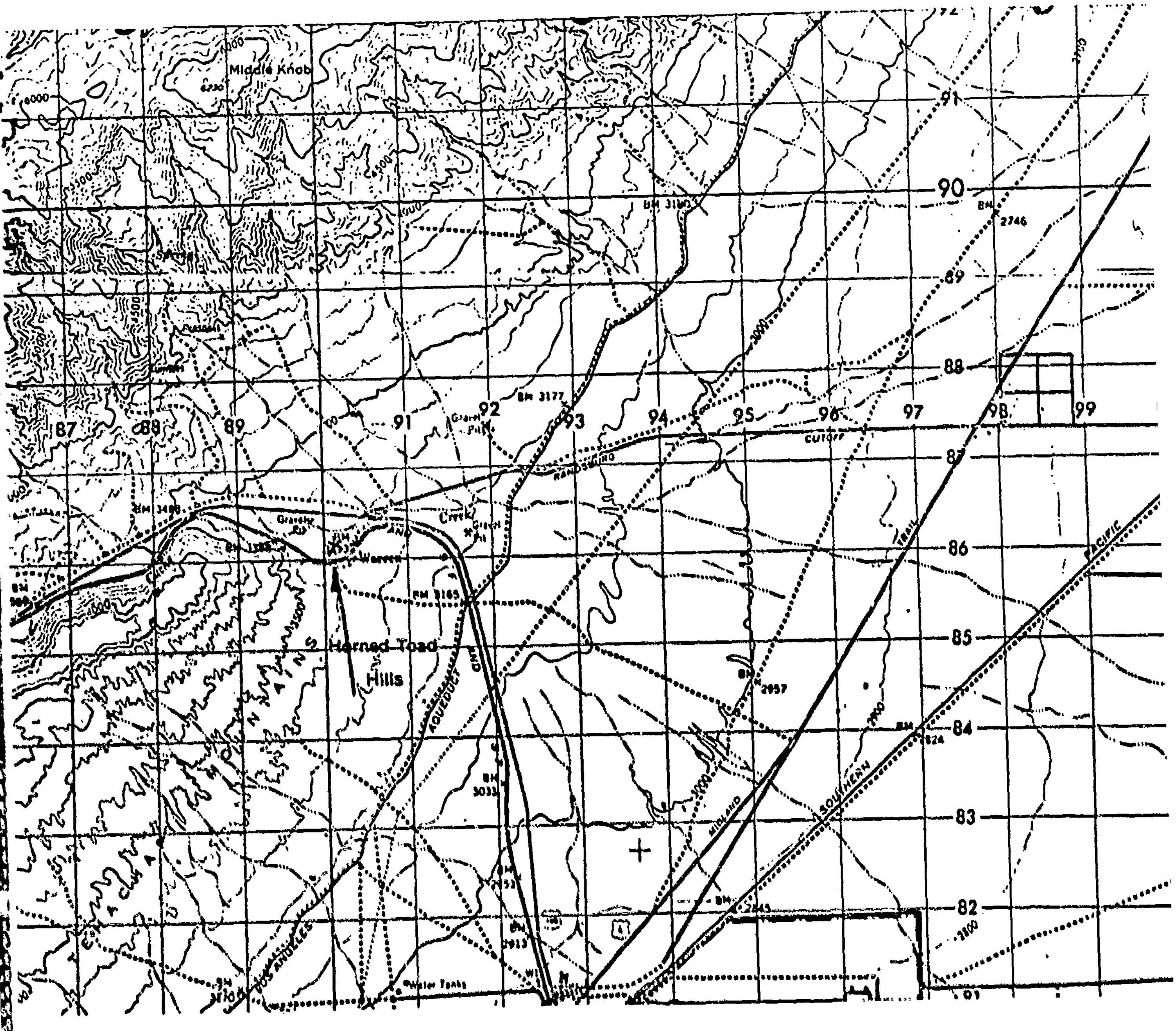

Figure A3. Mt. Pleasant location used for the MP slide.