THE GOOD, THE NOT-SO-BAD, AND THE UGLY: COMPUTER-DETECTED ALTITUDE, HEADING, AND SPEED CHANGES IN EN ROUTE AIR TRAFFIC CONTROL

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The relationship between communication events and controller workload has been well established. Unfortunately, a substantial amount of time and effort is required to transcribe and code these events. The present study examines computer-detected altitude, heading, and speed changes as possible alternatives to altitude, heading, and speed clearances. Two 20-minute samples of live air traffic data were collected from four sectors in the Kansas City en route airspace. The samples were parsed into 4-minute intervals, and both the number of clearances and computer-detected changes were tallied for each interval. In addition, 16 subject-matter experts provided matching Air Traffic Workload Input Technique (ATWIT) measures. Multiple regression analysis of altitude, heading, and speed clearances on mean ATWIT scores yielded an $R = .59$ ($R^2 = .35$). Multiple regression of the number of computer-detected altitude, heading, and speed changes yielded the same results. Multiple regression of the combined sets revealed that altitude changes alone could account for most of the variance in ATWIT scores. Results suggest that computer-derived altitude and heading changes may be a viable substitute for altitude and heading clearances. However, recorded ground speeds were too erratic to provide the basis for a valid measure of speed changes.

INTRODUCTION

Previous studies have shown that there is a relationship between communication events and controller workload (e.g., Bruce, 1993; Cardosi, 1993; Corker, Gore, Fleming & Lane, 2000; Morrow & Rodvold, 1998; Porterfield, 1997). However, it takes a considerable amount of time and effort to obtain these measures. First, audio recordings of all pilot and controller transmissions must be transcribed. Then, the transcriptions must be coded and the codes must be transferred to data files. To date, a satisfactory method for automating this process has not been developed. Consequently, the collection of communication events is time-consuming, labor-intensive, and subject to human error.

It would be preferable to develop alternative measures that might be more easily obtained. One possibility is the use of computer-detected changes in aircraft altitude, heading, and speed. Aircraft position information is routinely recorded by the en route Host computer system. Extraction of this information is fully automated, requiring minimal time and effort, and the resulting measures are completely objective.

In spite of the advantages of computer-detected measures, there is some question as to whether or not it is possible to develop algorithms sufficient to distinguish between random variability in aircraft position and actual changes. Computers rely solely on the adequacy of the parameters that have been set for them, and are generally unable to infer intent from partial information. Therefore, the first question to be answered has to do with the accuracy of computer-detected changes.

The second question to be answered has to do with the relationship between aircraft changes and controller clearances. We know that they do not necessarily share a simple “stimulus-response” relationship. Each has a separate set of associated workload factors. Prior to making a clearance, the controller must scan the airspace and make an assessment of the control situation. When the controller determines that a control action is necessary, then the decision must be made as to what particular control action will best fit the situation. Finally, there is the physical workload of issuing instructions to the pilot. In some instances, this includes making associated keyboard entries. After the clearance has been issued, another set of factors unfolds. First, the controller must make sure the clearance has been verbally acknowledged by the pilot and that the read back was accurate. The controller must monitor if the changes are being made in a timely manner and in accordance with the clearance. The controller must then evaluate whether the issued clearance was sufficient to produce the desired results or additional clearances will be necessary. Given the delay and differences between them, how well can changes in aircraft position capture the “echo” of the workload associated with controller clearances?

The present study examined these two questions using the Performance and Objective Workload Evaluation Research (POWER; Mills, Pfleiderer, & Manning, 2002) software system, transcripts of controller clearances, and subjective measures of controller workload. The first phase of the study compared controller clearances with computer-detected changes. The second employed linear multiple regression to examine the relationship between controller clearances, computer-detected changes, and subjective measures of air traffic controller workload.

METHOD

Traffic Samples

Traffic samples were derived from National Airspace System (NAS) System Analysis Recordings (SARs) using National Track Analysis Program (NTAP) reports to obtain recorded altitude, heading, and ground speed information for each aircraft in the sample. Information in the text-based NTAP reports was organized into Microsoft Access database files using the NAS Data Management System (NDMS) program. (For a description of these programs and their output, see Mills, Pfleiderer, & Manning, 2002.) Traffic samples were obtained from four sectors in the Kansas City (ZKC) Air Route Traffic Control Center (ARTCC). Two 20-minute samples were taken from each of the four sectors. As shown in Table 1, two were high-altitude sectors and two were low-altitude sectors.

For testing the concordance of controller clearances with computer-detected changes, the samples were processed using the diagnostic log option of the POWER program. For comparison with subjective measures of workload, the samples were POWER processed in 4-minute intervals, producing a total of 40 summary observations (i.e., the number of altitude, heading, and speed changes) for each measure.

Table 1. Kansas City Air Route Traffic Control Center (ARTCC) Samples

Sector/ Sample	Strata	Date	Sample Time (Local)
14A	High	01-20-99	07:16 - 07:36
14B	High	01-21-99	07:16 - 07:36
30A	High	01-21-99	09:40 - 10:00
30B	High	01-21-99	18:05 - 18:25
52A	Low	01-21-99	18:07 - 18:27
52B	Low	01-22-99	18:07 - 18:27
54A	Low	01-21-99	15:30 - 15:50
54B	Low	01-21-99	17:10 - 17:30

Controller Clearances

Controller clearances were obtained from voice tapes associated with the eight ZKC traffic samples. Time-stamped audiotapes of pilot and controller transmissions were transcribed and coded for content. All controller transmissions pertaining to altitude, heading, and speed clearances were extracted to construct a database containing transmission start time, transmission stop time, message content, and the type of clearance issued. For comparison with subjective measures of workload, the clearances were tabulated in 4-minute intervals, producing a total of 40 summary observations.

Subjective Workload Measures

Subjective workload measures were contributed by 16 en route air traffic control instructors from the FAA Academy in Oklahoma City. All had formerly been Certified Professional Controllers (CPCs) at various en route centers across the United States. The participants received airspace training for each of the four sectors included in the traffic sample and then observed SATORI (Systematic Air Traffic Operations Research Initiative; Rogers & Duke, 1993) re-creations of the live air traffic data. SATORI synchronizes extracted SAR data with voice tapes to produce graphical re-creations of air traffic events. Participants provided subjective workload estimates using the Air Traffic Workload Input Technique (ATWIT; Stein, 1985). The ATWIT measures mental workload in "real-time" by presenting auditory and visual cues that prompt the participant to press one of seven buttons within a specified amount of time to indicate the level of mental workload experienced at that moment. Participants were prompted every four minutes during each traffic sample to provide an estimate of the amount of subjective workload they thought the radar controller responsible for the sector was experiencing at the time of the prompt. These assessments were summarized to produce a total of 40 mean subjective workload estimates.

Computer-detected Changes

Preliminary parameters for change detection were based on the *Private Pilot – Airplane Practical Test Standards* (FAA, 1995) that establishes guidelines for pilots regarding acceptable variability in altitude, heading, and speed. This seemed the best place to begin, since deviations beyond "acceptable variability" suggest that the aircraft was, in fact, responding to a clearance. Because Host computer system "glitches" sometimes occur in the recording of altitude, heading, and speed information (e.g., missing values recorded as an altitude of zero) an outlier criterion was established to ensure they would not be recorded as actual changes. A total of 900 individual flights (i.e., 300 flights for each type of change) were evaluated to determine the ability of the algorithms to detect altitude, heading, and speed changes. Accuracy of the computer-detected changes was tested by visual examination of graphs of each aircraft's altitude, heading, or speed that had been color-coded to highlight change parameters. Initial parameters were adjusted based on these evaluations.

RESULTS

Comparison of Clearances With Computer-detected Changes

Bivariate correlations of tabulated clearances and changes were not an effective means of evaluating concordance because of interval processing (i.e., changes occurring in the interval following the issued clearance). Therefore, clearances were manually paired with their corresponding changes. Several criteria were used for pairing, including temporal proximity of the clearance to the change, the direction of the change, and whether the final recorded altitude, heading, or speed was comparable with the clearance issued.

Altitude. The proportion altitude clearances paired and unpaired with computer-detected changes is shown in Table 2. The majority of unpaired altitude clearances were the result of transfer of control. In most cases, the controller issued a clearance for the aircraft to climb or descend to the vertical boundary of the adjacent sector and then immediately transferred control of the aircraft. The change was not detected because the aircraft was no longer under the sector's control when it complied with the altitude clearance (note that all of these changes *were* detected when data from the adjacent sectors were processed, raising the proportion of paired altitude clearances and changes to approximately 97%). Other causes for failure to pair altitude clearances with computer-detected changes included one garbled aircraft identifier, one case of non-compliance (i.e., the pilot never followed the controller's instructions), and one clearance to "stay at present altitude."

Table 2. Summary of Altitude Clearance/Change Pairs

	Altitude Clearances
Paired	71 (84%)
Unpaired	14 (16%)
Total	85

Heading. The proportion of heading clearances paired and unpaired with computer-detected changes is shown in Table 3. Two of the unpaired clearances were issued just before control of the aircraft was transferred to another sector. One could not be paired because the aircraft could not be identified (i.e., the stated aircraft identifier did not correspond with any of the controlled aircraft in or around the sector). In another case, the issued clearance was less than the minimum criterion of 10°. The remaining unpaired clearances were the result of changes that occurred too slowly to be detected.

Table 3. Summary of Heading Clearance/Change Pairs

	Heading Clearances
Paired	21 (72%)
Unpaired	8 (28%)
Total	29

Speed. The proportion of speed clearances paired and unpaired with computer-detected changes is shown in Table 4. Most of the unpaired speed clearances were caused by the relationship between speed and other types of changes. Consider the flight data from one of the ZKC samples shown in Figure 1. Just prior to the first data point in the graph, the pilot was given a clearance to reduce speed to 250 knots; by 13:34:26 the aircraft had begun to gradually slow. However, when the aircraft made a slight heading change there was a drastic change in recorded ground speed (13:35:20). As soon as the turn ended, the aircraft's recorded ground speed suddenly dropped to a level suggesting the aircraft had actually continued to slow gradually during the heading change (13:35:32). When the aircraft made another subtle heading shift there was another dramatic increase in recorded ground speed (13:35:44), followed by a sharp decrease in recorded ground speed the instant the turn was completed (13:35:56). Needless to say, the speed change in the example was undetected (due to interference and outlier effects) and unpaired with its corresponding clearance. Analogous changes in recorded ground speeds were found with respect to altitude changes. It was clear from this and numerous similar examples, that recorded ground speed was extremely erratic and unreliable when altitude and heading changes were being made.

Table 4. Summary of Speed Clearance/Change Pairs

	Speed Clearances
Paired	12 (55%)
Unpaired	10 (45%)
Total	22

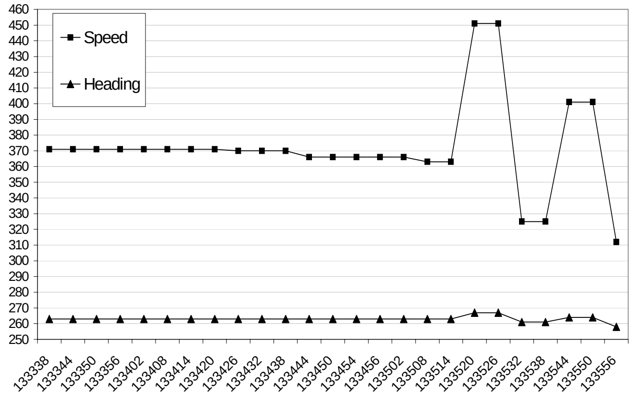

Figure 1. Example of Changes in Ground Speed Relative to Heading Changes

Relationship of Clearances and Changes With Subjective Measures of Workload

Multiple regression analysis was employed to examine the relationship between controller clearances and computer-detected changes with subjective controller workload. Two comparative analyses were conducted to examine the amount of variance explained by each set of predictors. A third analysis, using the combined variable sets, examined the amount of shared variance among the predictors. Note that the purpose of these analyses was to evaluate the relationship of the selected variables with the criterion. These variables were not intended to represent a comprehensive list of all possible predictors of subjective controller workload.

Table 5. Standard Multiple Regression: Clearances on ATWIT Measures ($N = 40$)

Model Summary	***R***	***R*^{2}**	**Adj. *R*^{2}**	***S.E.***	***F***
	.59	.35	.30	.496	6.49**

Coefficients	***sr*^{2}**	***b***	***β***	***t***
Altitude	.21	.18	.473	3.45**
Heading	.01	.06	.082	0.59
Speed	.09	.27	.308	2.28*

** p < .01; * p < .05

Table 6. Standard Multiple Regression: Changes on ATWIT Measures ($N = 40$)

Model Summary	***R***	***R*^{2}**	**Adj. *R*^{2}**	***S.E.***	***F***
	.59	.35	.29	.497	6.40**

Coefficients	***sr*^{2}**	***b***	***β***	***t***
Altitude	.12	.15	.474	2.58*
Heading	.02	-.08	-.238	-1.06
Speed	.02	.08	.300	1.11

** *p* < .01; * *p* < .05

Table 7. Standard Multiple Regression: Clearances and Changes on ATWIT ($N = 40$)

Model Summary	***R***	***R*^{2}**	**Adj. *R*^{2}**	***S.E.***	***F***
	.67	.44	.36	.472	5.43**

Coefficients	***sr*^{2}**	***b***	***β***	***t***
Altitude Clearances	.07	.12	.311	2.10*
Altitude Changes	.09	.13	.390	2.38*
Heading Clearances	.01	.07	.093	.67
Heading Changes	.01	-.04	-.104	-.69
Speed Clearances	.04	.19	.218	1.61

** p < .01; * p < .05

As shown in Table 5, the multiple regression model of altitude, heading, and speed clearances produced a multiple R=.59 and accounted for approximately 35% of the variability in ATWIT scores. Both altitude clearances and speed clearances contributed significantly to the model, but heading clearances did not. "In semipartial correlation, the contribution of other IVs is taken out of only the IV. Thus, the squared semipartial correlation expresses the unique contribution of the IV to the total variance of the DV" (Tabachnick & Fidell, 1989, p. 151). The difference between R^2 and the sum of sr^2 for all predictors in the variable set represents shared variance. Therefore, 31% of the variance explained by this variable set was unique, whereas only 4% was shared.

The regression model based on computer-detected changes, shown in Table 6, also produced a multiple R=.59, and accounted for approximately 35% of the variability in ATWIT scores. However, only altitude changes contributed significantly to this model. In this model, 16% of the explained variance was unique and 19% was shared. This indicates that changes were more correlated with one another than were clearances – not surprising given the previously mentioned relationship between changes in ground speed with changes in altitude and heading.

The regression models shown in Tables 5 and 6 demonstrate that both variables sets (i.e., controller clearances and computer-detected changes) are able to explain approximately the same amount of variance in subjective workload. However, this does not necessarily mean that they describe the *same* variance. Squared semipartial correlations of the standard multiple regression analysis of both clearances and changes on ATWIT scores (shown in Table 7) indicate that approximately half (22%) of the 44% explained by the model is shared. (Note that speed changes were excluded from this analysis due to concerns about the accuracy of the variable. It is possible that a larger portion of the explained variance would have been shared had speed changes been included.) Both altitude changes and clearances contributed significantly, but altitude changes explained slightly more unique variance (9%) than did altitude clearances (7%).

CONCLUSIONS

The Good. The results of both the tests for concordance and multiple regression analyses demonstrated that altitude clearances and computer-derived altitude changes were strongly related. Though altitude clearances and computer-detected altitude changes did not describe the exact same variance, they were sufficiently related to reduce the amount of unique variance each was able to describe when used in combination in a multiple regression analysis. These results indicate that computer-detected altitude changes might be a viable substitute for altitude clearances in predicting subjective workload.

The Not-So-Bad. The number of heading changes that occurred too gradually to be detected suggested that the heading change algorithms require some revision. A more detailed analysis of heading changes inherent to flight plans and similar sources (i.e., changes in the absence of a clearance) must be conducted before it will be possible to fully determine the accuracy of the algorithms. Although heading changes (and clearances) failed to explain a significant amount of the variance in subjective controller workload, this may not be the case in all traffic samples. Certainly additional analyses using other traffic samples will be necessary to fully evaluate the potential of (revised and improved) computer-detected heading changes as a possible alternative for heading clearances.

The Ugly. On the other hand, ground speeds recorded by the Host computer (and displayed on the controllers' radarscope) proved to be too erratic and unreliable to provide a valid measure of speed changes. Computer-detected measures based on this information cannot be recommended as an acceptable alternative for speed clearances. This is unfortunate, because the results of the regression analysis indicated that controller speed clearances were able to describe a significant amount of unique variance in subjective controller workload. Therefore, it may be worth the time and effort involved to investigate other sources of speed information from which to develop computer-detected measures of speed changes.

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