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Using Grounded Theory techniques to develop models of aviation student performance

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Abstract

A frequently encountered issue in both aviation training and aviation training research is that of student performance modelling. A potentially rich source of student performance data exists in many if not all aviation training organisations in the form of narrative reports written after flying or simulator sorties. This paper describes how grounded theory technique, developed by Glaser and Strauss (1967) was used to perform sampling and analysis of such data to develop a model of student performance. The application of the technique is illustrated with a case study from the military flying training domain.

Introduction

A frequently encountered issue in aviation training research is that of student performance modelling. A potentially rich source of student performance data exists in many if not all aviation training organisations in the form of narrative reports written after flying or simulator sorties. The challenge is in finding a suitable way to sample and then analyse the data in these reports to produce a meaningful model.

Grounded theory technique, however, developed by Glaser and Strauss (1967), provides a rigorous and structured method to perform sampling and analysis of

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such unstructured data. Strauss and Corbin (1990) defined grounded theory as follows:

> *'A grounded theory is one that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon…One does not begin with a theory then prove it. Rather, one begins with an area of study and what is relevant to that area is then allowed to emerge.'* (p. 23)

The application of this technique is illustrated with a case study from the military flying training domain.

Background to the study

A performance model was required for fighter crews undergoing initial training in pairs combat techniques on the Royal Air Force Panavia Tornado F3 Operational Conversion Unit (OCU). The main course run by the OCU was designed to train fighter crews (pilots and navigators) in the operation of the Tornado F3 in the air combat role. The final phase of the course focussed on pairs tactics. The use of a pair of visually supporting aircraft has formed the basis of virtually all air combat tactics since aircraft have been used in combat (Tornado F3 Training Course Pairs brief, 1998). Leadership of a pair of aircraft is heavily dependent on effective communication between the aircraft crews, as they have to build and maintain situation awareness whilst engaged in a fast moving, three-dimensional fight and make appropriate tactical decisions.

The results of a task analysis of Beyond Visual Range (BVR) intercepts conducted by Houk, Whitaker and Kendall (1993) were used by Waag and Houk (1994) to derive a set of behavioural indicators suitable for evaluating proficiency in air combat in day to day squadron training. They identified communication, information interpretation and decision-making as key activities. Bell and Lyon (2000) reported that communication was one of the most highly rated elements contributory to good situation awareness, based on a survey of mission ready McDonnell-Douglas F-15C fighter pilots. A high level of situation awareness was also identified as a critical component for effective decision making by Endsley and Bolstad, (1994). Furthermore, it has been argued that the process of situation assessment (encompassing such activities as communication and information interpretation) is a fundamental precursor of situation awareness, which is itself the precursor for all aspects of decision-making (Nobel, 1993; Prince and Salas, 1997). These propositions put forward in these studies are also consistent with the model of situation awareness and its position in the decision-making, action-taking loop proposed by Endsley (1995).

Anecdotal evidence from the instructors on the OCU suggested that students were weak at communication during this final phase of training. They attributed this to the unsuitability of the ground training device in use, which only took a single crew. A multi-player simulator was to be evaluated to determine if it produced positive transfer of training to the airborne environment for pairs training. The empirical evidence, in the form of archived narrative reports of past student performance in the pairs phase, was investigated in order to develop a student performance model. This model was required both to validate the anecdotal evidence from the instructors about students' performance, and to subsequently inform the development of suitable behavioural indicators for the evaluation of the multi-player simulator.

Method

Overview

The approach taken to applying grounded theory to this study was based on the procedures and techniques suggested by Strauss and Corbin (1990). Figure 1 shows the sequence of steps that were followed.

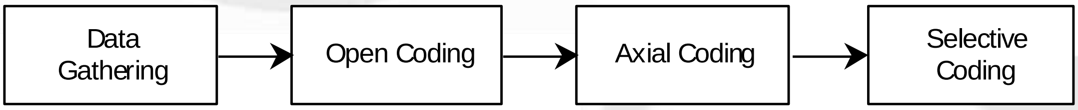

Figure 1 Grounded theory application steps (from Strauss and Corbin, 1990).

The following sections describe the nature of each of these steps and the methods that were employed in implementing them.

Data gathering

The data were collected from pairs-phase sortie reports using what Strauss and Corbin (1990) describe as a line-by-line analysis technique. Reports were selected from courses completing the pairs phase during a three-month period. Each report was broken down into individual sentences or small groups of sentences that referred to a single observation about an aspect of performance. Three sampling criteria were employed at this stage. The first element was concerned with the selection of observations directly relevant to practice intercepts (sortie reports covered the whole of the sortie from starting up the aircraft and taxiing out to the recovery back to base). The second element of sampling was aimed at achieving a balanced view of both pilot and navigator assessment issues. To achieve a representative sample covering all performance aspects of the practice intercepts approximately 100 comments for each crew member were selected from the sortie reports. The final sampling criterion was to select from as wide a range of instructors who had written the assessments as possible.

Open coding

Open coding is defined by Strauss and Corbin (1990) as:

> *'The process of breaking down, examining, comparing, conceptualising and categorising data.'*

The tabulated comments produced by the line-by-line analysis during data gathering were analysed to identify categories into which they could be grouped. This analysis was conducted using the constant comparison technique, as described by Partington (2002), whereby each data item was compared with preceding items to see if it described the same phenomenon as one of the items and therefore could be allocated to an existing category, or if a new category needed to be developed. The application of this to the set of instructor comments by the first rater yielded an initial set of coding categories. The comments were then re-coded using these categories by a second rater, to check for inter-rater reliability. Differences in coding were discussed and resolved to produce an agreed list of categories.

Axial coding

Strauss and Corbin (1990) define axial coding as:

> *'A set of procedures whereby data are put back together in new ways after open coding, by making connections between categories.'*

The output from this stage was a set of higher order categories describing student performance along with a description of the nature of the connection between the lower order categories that they contained. This required a detailed re-evaluation of the comments within each category.

Selective coding

Selective coding is defined by Strauss and Corbin (1990) as:

> *'The process of selecting the core category* [and] *systematically relating it to other categories.'*

They also point out that this process is essentially similar to axial coding, but is conducted at a higher level of abstraction. The core category is the over-arching phenomenon or concept that links each of the categories or phenomena that are developed during axial coding. After the core crew performance category had been identified, the links between the categories identified during axial coding were revealed through further analysis of the comments in each category. Once all the categories had been linked together to form a complete model, a narrative description was developed.

Performance model development

Data

A total of 200 performance comments were collected from 46 sortie reports. There was an even split of navigator and pilot student reports. Twenty-eight (80% of the instructor population) completed reports that were used in the sample.

Open coding

The open coding process conducted by the first investigator yielded eight initial coding categories, shown in the first column of table 1. During the open coding process it was noted that the performance comments could be categorised as being either positive or negative comments. Each comment was annotated accordingly. Columns two and three of table 1 show the frequencies of positive and negative comments or each of the initial coding categories that were identified. Column four shows the total number of comments allocated to each category. A striking feature of the data was that 89 out of 200 (45%) of the performance statements were related to communications.

When the second investigator then re-coded the performance statements, using the categories identified by the first investigator, agreement was achieved for 70% (140) of the performance statements.

During the subsequent discussion between the investigators to resolve differences of opinion about coding categories, the most problematic category was 'decision-making'. In 40 of the 60 instances where there was a disagreement, the issue was whether a statement should be categorised as 'decision-making' or whether it should be categorised as 'weapons employment', 'communications' or 'tactics'. In the subsequent discussions it was identified that decision-making was taking place in a range of contexts and that new categories may have been appropriate for 'weapons decision-making' and 'communications decision-making'. The following statement about 'communications' was one of a number of statements illustrated that a 'communications decision-making' category was justified:

'If things are worth saying to your pilot, they could be worth transmitting.'

This statement suggested that, on some occasions at least, the student should have decided to communicate with the other aircraft and didn't. Similarly, statements were found that supported the creation of a 'weapons decision-making' category.

Table 1 Initial open coding categories and positive, negative and total comment frequencies for each category.

Initial Open Coding Category	Frequency of Positive Comments	Frequency of Negative Comments	Total Number of Comments
Communications	26	63	89
Weapons Employment	5	21	26
Situation awareness	6	20	26
Tactics	7	17	24
Decision Making	6	12	18
RHWR Awareness	2	4	6
Use of Chaff and Flare	3	4	7
Leadership	2	2	4
Total	**57**	**143**	**200**

Having identified that the communications and weapons employment categories could in part be decomposed in to related decision-making sub-categories, the view was taken that theoretical sensitivity had strongly influenced the development of the initial open coding categories. 'Communications' was expected as a category given that it featured centrally in the research question being addressed and this could account for the underlying categories being overlooked initially. The constant comparison technique was applied again to the statements in the 'communications' and 'weapons employment' categories to see if data supported this view.

In the case of the remaining 'weapons employment' statements it was found that they were all concerned with the operation of the weapons system, hence the 'weapons system operation' category was introduced. The 'communications' category statements were found to relate to the passing of information in different contexts. Further application of the constant comparison technique to these statements yielded sub-categories for 'passing tactical situation and actions', 'giving tactical orders' and 'passing missile shot information'.

As with 'communications', 'situation awareness' had been expected as a category and comments about it were often placed under a heading of 'situation awareness' in the narrative reports by the instructors. Re-analysis of the set of comments made about ‘situation awareness’ revealed that the instructors viewed ‘situation awareness’ as a set of processes (q.v. ‘situation assessment’). The need for students to monitor displays and communications as sources of information for situation awareness is highlighted in comments such as:

> *‘At times his situational awareness was not as high as it should have been, he must build it through listening and monitoring the tactical display.’*

Other statements implied that ‘situation awareness’ also involves processing this information in some way in order to make judgements. For example, the following statement indicates that evaluation of the bandits’ (enemy) actions and anticipation of their possible intentions were considered essential activities:

> *‘... situational awareness – don’t just say what the bandits are doing – try to draw some conclusions about their behaviour and our RHWR* [Radar Homing and Warning Receiver] *indications’*

Based on this analysis, the ‘situation awareness’ category was decomposed into ‘monitor’, ‘evaluate’ and ‘anticipate’ sub-categories (effectively the ‘situation assessment’ processes underpinning ‘situation awareness’).

Finally, it was identified that all of the statements categorised as either ‘decision-making’ or ‘tactics’ by the first investigator could be accurately described as referring to tactical decision-making. Consequently, the ‘tactics’ and ‘decision-making’ categories were merged to create a single ‘tactical decision-making’ category.

Table 2 Initial and final open coding categories.

Initial categories	**Final Categories**			
Communications	Comms decision making	Pass tactical situation/ actions	Give tactical orders	Pass missile shot information
Weapons Employment	Weapons decision making		Weapon system operation	
Situation awareness	Monitor	Evaluate		Anticipate
Tactics	Tactical Decision Making			
Decision making				
RHWR awareness	RHWR awareness			
Use of chaff and flares	Use of chaff and flares			
Leadership	Leadership			

The remaining categories were found not to subdivide. The final agreed set of categories is shown in the second column of table 2.

Axial coding

During the open coding stage, ‘decision-making’ was identified as a central component of ‘tactics’, ‘weapons employment’ and ‘communications’. The instructor comments in the remaining categories were reviewed to identify if it occurred elsewhere. All the statements in the ‘use of chaff and flares’ category were also found to refer to decision-making. For example:

> ‘[Use] *flares at the correct range otherwise, as you saw, you will get a Fox 2* [infra-red guided missile] *in the face’*

Clearly, a poor decision about flares usage could have fatal consequences. The operation of chaff and flares is a matter of a button press so it is not surprising that there were no statements about chaff and flares operation. From this analysis, ‘decision-making’ was identified as a high-level category which included the ‘communications’, ‘weapons’ and ‘tactical decision-making’ categories along with the ‘use of chaff and flares’ category.

During open coding, ‘situation awareness’ was decomposed into the underpinning process activities of ‘monitoring’ the environment, ‘evaluating’ this information and ‘anticipating’ future events (situation assessment). The following comment suggested that the ‘RHWR awareness’ could also be regarded as an aspect of monitoring the environment:

> *‘He is not monitoring his RHWR, he made no mention of threat indications – he must bring it into his scan’*

Therefore, this category was subsumed within the ‘monitoring’ category. ‘Situation awareness’ was reintroduced but as a high level category containing the previously mentioned sub-categories describing the processes of ‘monitor’, ‘evaluate’ and ‘anticipate’.

The open coding categories of ‘weapons system operation’, ‘passing tactical situation/actions’, ‘giving tactical orders’ and ‘passing missile shot information’ could be construed as actions taken in response to decisions. Thus, the ‘actions’ category was created containing these sub-categories. ‘Leadership’, the remaining open coding category, was not considered to fit into any other category.

Selective coding

The key to the selective coding stage and the subsequent development of an overall model was the identification of the core category. This was required in order to facilitate the integration of the 'decision-making', 'action' and 'situation awareness' and 'leadership' categories identified in the axial coding stage. As a result of re-examining the full set of statements, the following statement was identified which pointed to a potential core category:

'... he must be more missile launch success zone aware, he was generally trying to do all things rather than the main priority – killing the bandit.'

The significance of this statement is that it identified the primary goal of all the activities engaged in during the practice intercepts, which was killing the enemy.

The next stage was to identify the relationships between high-level categories. The connection between 'decision-making' and 'actions' was simple; actions were taken in response to decisions made. The connection between 'situation awareness' and these categories had to be established. A clear insight into the purpose of situation awareness, namely that it informs decision-making, was given by the statement:

'... he lost situational awareness momentarily and shot at his wingman'

In this instance poor situation awareness resulted in an erroneous weapon employment decision. The question then arose as to what happened once an action had been taken? A number of comments pointed to the iterative nature of the process such as:

'If a missile shot does not come off shoot again or reposition'

The inference drawn from this comment was that following an action the situation had to be monitored and re-evaluated so that subsequent decisions could be taken and actioned.

Further analysis of the leadership statements showed that effective leadership of the pair during the intercept required good situation awareness and sound decision-making and was implemented though effective communication.

Discussion

Figure 2 shows the complete performance model, with situation awareness, decision-making and action categories broken down into their sub-components. The central feature of the model is the constant repetition of development of 'situation awareness' leading to 'decision-making' and subsequent 'actions'. 'Communication' is prominent, both as an aspect of decision-making and as a required action following decision-making. These features of the model were consistent with the findings of Waag and Houk (1994) in their development of a set of behavioural indicators suitable for evaluating proficiency in air combat in day-to-day F-15 squadron training. They identified communication, information interpretation and decision-making as key activities. This point is reinforced by Bell and Lyon (2000) who reported that communication was one of the most highly rated elements contributory to good situation awareness, based on a survey of mission ready F-15C fighter pilots. The monitor-evaluate-anticipate model of situation awareness was found to be directly equivalent to the perception-comprehension-projection model of situation awareness proposed by Endsley (1995). Therefore, the student performance model that was developed was considered to be highly consistent with the published models of air combat and situation awareness. The OCU instructors reviewed the model and agreed that it was consistent with their perception of the air combat task and accurately captured student weaknesses in performance.

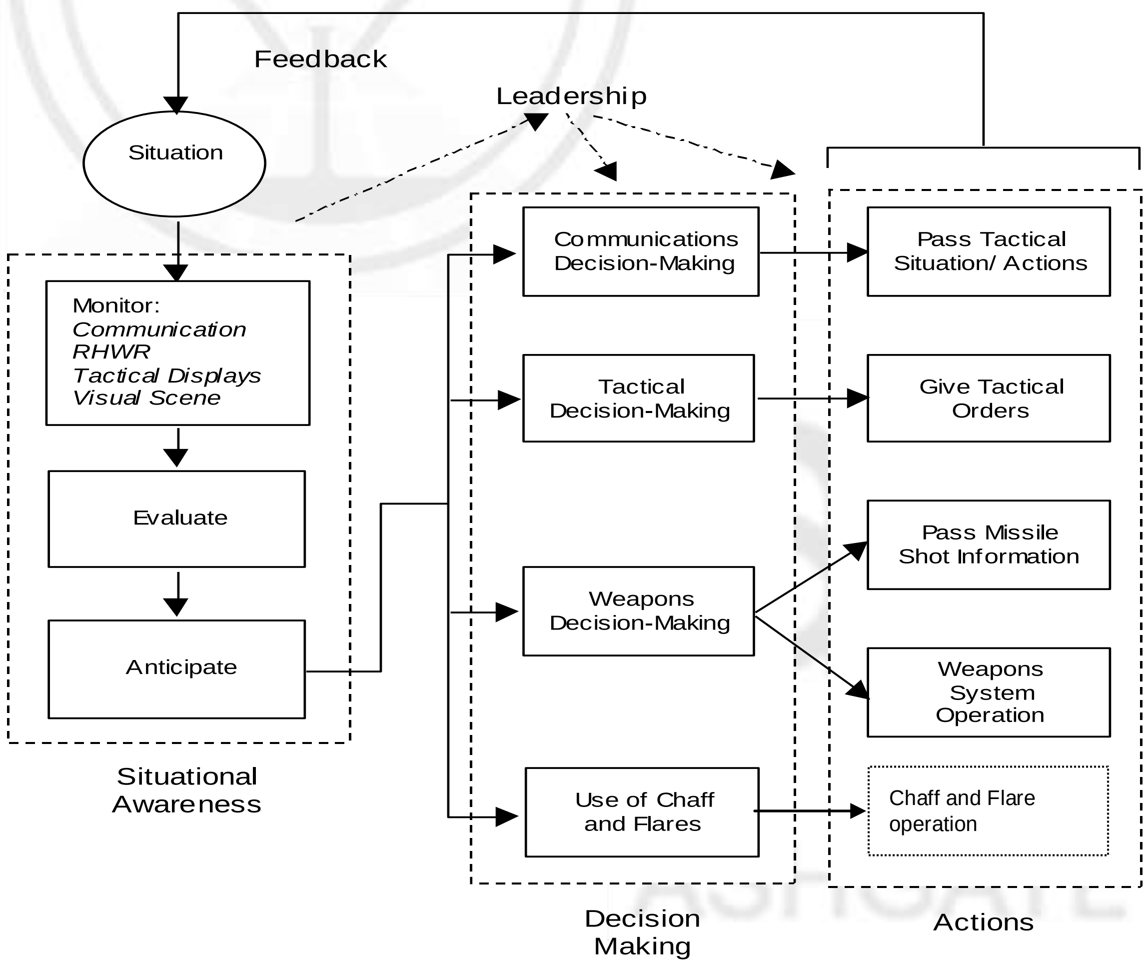

Figure 2 Detailed student performance model

One of the instructors responsible for teaching sessions on the use of the radar during the basic radar phase at the start of the course commented that the model developed was very close to the model which he taught, shown in figure 3.

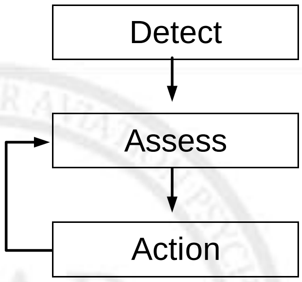

Figure 3 Instructor model for radar use.

In this model the detect component referred to the initial search for target aircraft. Once a target had be spotted, the assess stage covered the monitor, evaluate and anticipate components of situation awareness. The action component referred to the decision-making action sequence. The parallel between this model and that developed through the grounded theory study adds support to the argument that the model produced was valid. It also supported the view that, by definition the items that were considered important for comment reflected the training priorities of the instructors and as such represented the model of air combat that they were teaching.

The grounded theory techniques applied during this study provided a powerful toolset for the analysis of the sortie report data, enabling a detailed model of student performance during the pairs phase to be built.

Returning to the initial objectives of the study the principal reason for developing the model was to validate the instructors' view, expressed anecdotally, that communications were a major area of weakness in student performance in the pairs phase. The analysis of the number of comments in each of the categories identified in developing the model showed that 45% of the comments were made about communications and that the majority of those were negative, validating the instructors' perception that students' performances were weak in the area of communications. Weaknesses in the areas of 'situation awareness' and 'decision-making' were also exposed. The presence of both positive and negative comments in each of the open coding categories that were developed was interpreted as indicating that these aspects of performance were considered to be important by the instructors as they were choosing to comment on performance in these areas regardless of whether or not a student had made a mistake. Indeed, the grounded theory analysis clearly identified eight basic areas (and nine further sub-areas) for meaningful assessment of student performance in the Tornado F3 pairs phase. Therefore, the model provided a sound basis upon which to determine candidate measures for a subsequent training effectiveness trial.

From a methodological perspective, the grounded theory techniques applied during this study facilitated rigorous analysis of the sortie report data, enabling a detailed model of student performance during the pairs phase to be built. Investigator triangulation was found to be essential in order to reduce bias caused by theoretical sensitivity. It is suggested that Grounded Theory is a technique that is very well suited to the analysis of qualitative performance data in the form of narrative reports which are commonly used in the aviation training domain.

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