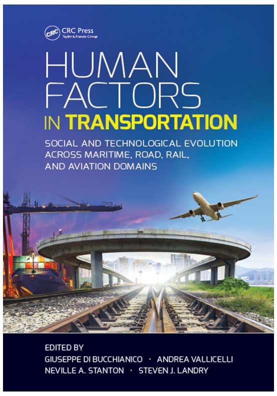

Human Factors in Transportation
Social and Technological Evolution Across Maritime, Road, Rail, and Aviation Domains

Giuseppe Di Bucchianico, Andrea Vallicelli, Neville A. Stanton, Steven J. Landry

Identifying Markers of Performance Decline in Air Traffic Controllers

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Identifying Markers of Performance Decline in Air Traffic Controllers

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26.1 Introduction

Air traffic control (ATC) is a complex and highly dynamic safety-critical environment. Within this environment, air traffic controllers (ATCOs) are responsible for flight safety and efficiency. Unlike other safety-critical industries, there are no physical barriers or defenses that protect aircraft in flight. It is therefore essential that ATCOs maintain a consistently high standard of human performance to maintain flight safety.

With a large potential for incidents, air traffic management (ATM) is remarkably reliable (Amalberti and Wioland, 1997). However, it is widely documented that human factors, such as workload and fatigue, are the "major determinants of human error" (Park and Jung, 1996, p. 330) and can negatively influence human performance in air traffic control environments (e.g., Cox-Fuenzalida, 2007; Edwards, Sharples, Wilson, and Kirwan, 2012). Traditionally within the discipline of human factors, the investigation of human performance and the association with potential performance-influencing factors has focused on a wide range of methods, from laboratory experiments to "research in the wild" (Sharples, Edwards, and Balfe, 2012). However, little research has focused on the identification and application of "signs and symptoms," or indicators, of the negative association between human factors and performance, that is, indicators that may provide a signal that a controller is reaching their personal "edge" of performance.

Previous research aligned with this topic has typically focused on the identification of control strategies utilized to support controllers in maintaining performance under demanding conditions. For example, Sperandio (1971) identified that controllers utilized adaptive strategies to manage the increases in traffic load by decreasing the amount of time processing each aircraft. This workload regulation enabled the performance to be maintained in conditions that otherwise would have led to an excessive workload (called an "overload" situation) (Wickens, Mabor, and McGee 1997). In addition, Kontogiannis and Malakis (2013) identified behavioral markers for air traffic control strategies that were applied to cope up with complex situations. This research has provided a valuable insight into the maintenance of performance under demanding conditions in an air traffic environment. However, a comprehensive set of indicators that show when controllers are reaching their edge of performance, developed based on real-world operations, has not yet been identified.

The investigation of indicators of performance decline has both theoretical and practical motivations. The identification of behavioral indicators that may be associated with performance will contribute to the relatively sparse literature on behavioral indicators of performance (Sharples et al., 2012). A practical application of the findings is a contribution to the identification of indicators of potential performance decline, enabling those in operational contexts to put mitigations in place before system performance and safety degrades. The research presented in this chapter aims to address this gap in research by identifying indicators that controllers may be reaching their edge of performance, based on data from real-world operations. The principal aim of the research presented in this chapter was to generate expert opinion regarding the indicators of potential performance decline in an ATC setting. A subaim was to identify indicators that were commonly associated with specific human factor influences (e.g., workload influences) on performance.

26.2 Method

26.2.1 Design

A total of 22, 1 hour, face-to-face semistructured interviews were conducted with en-route ATCOs. The sample was a nonprobability purposive sample. Participants were recruited by Maastricht Upper Area Control (MUAC) center managers, and selected to represent subgroups of controllers based on age, sex, experience, and role. The number and length of interviews was based on pragmatic considerations. Interviews took place at MUAC, in the Netherlands. A protocol was used to standardize the interview procedure. An interview schedule was developed to guide the semistructured interview; participants were asked predesigned lead questions that were then followed by probes.

Workload, stress, and situation awareness (SA) had been identified through previous studies (Edwards, Sharples, Wilson, Kirwan, and Shorrock, 2010) as three human factors that were important in an ATC environment, and had the potential to influence ATCO performance. Therefore, these factors were specifically selected to be included in the interviews to further explore the relationship between these factors, associated indicators, and performance decline in ATCOs. Participants were provided with definitions of each factor, developed during a previous study from a review of the literature and feedback from two ATCOs (Edwards et al., 2010). For the factor of workload, as the task of an ATCO is primarily cognitive, the interviews focused specifically on mental workload. The definition utilized for workload was "experienced demand (amount and complexity) imposed by ATC tasks, and associated subjective perception of effort to meet demands." Task demand (also referred to as taskload) and workload were differentiated during the interviews; task demand was described as the objective demands of a specific task or situation, compared to workload that refers to the individual's perception of the objective task demands and the capability of the individual to meet those demands. In relation to the factor of stress, stress was defined as "pressures imposed by situations which challenge the controller's ability to cope." Several stressors exist within the ATC environment that can influence the perception of stress, and ATCO performance. The third factor that was included in the interviews was situation awareness (SA). SA is important for a successful performance in ATC (Endsley and Rodgers, 1994). ATCOs must continually assess dynamic information sources to develop a mental representation of aircraft in three-dimensional (3D) space and projected the future aircraft locations. Controllers call this "the picture" (Endsley and Rodgers, 1994). The definition of SA used in this chapter was "maintenance of a coherent mental picture for current and future events based on continuous extraction of environmental information, which includes controller performance."

Participants were first asked about their experience of the existence and use of indicators of potential performance decline in an ATC domain. Participants were then asked to list the indicators of potential performance decline that were perceived to be associated with the specific factors of workload, stress, and SA (e.g., "What indicators of potential performance decline are associated with the influence of high workload on performance?"). Interviews were tape recorded and were then orthographically transcribed. Thematic analysis (Strauss and Corbin, 1990) was applied as the analysis strategy.

26.2.2 Participants

In total, 22 en-route controllers were interviewed. The majority of participants were male (17, or 77.27%), compared to female participants (5, or 22.73%). All participants worked as en-route controllers in the Maastricht Upper Airspace control (MUAC) center. Participants' ages ranged from 21 to 60. Participants responded to grouped age ranges and so an average age could not be calculated. A total of five participants (22.72%) were in the 21–30 age range, and a majority of nine participants (40.9%) were in the 31–40 age range. A total of seven participants (31.81%) responded to the 41–50 age range and one participant was in the 51–60 age range (4.54%). All participants were qualified ATCOs who had completed training. Years of experience as an ATCO (excluding training) ranged from 1.5 to 31 years (M = 14.55, SD = 8.68). A total of 15 participants had worked as an on-the-job training instructor (OJTI). Years of experience as an OJTI ranged from 2 to 25 years (M = 10.93, SD = 7.11). In total, six participants were also supervisors. The experience as a supervisor ranged from 1.5 to 11 years (M = 6.08 years, SD = 3.56).

26.2.3 Materials

A schedule was designed to structure the interview, which comprised of 11 open-ended lead questions relating to four areas of interest:

1. Meaning and use of indicators in ATC settings
2. Categorization of indicators of human performance limits
3. Indicators associated with specific human factors (workload, stress, and SA)
4. Awareness of own indicators and colleagues' indicators

The interview schedule was reviewed and approved by two human factors experts and two ex-controllers. The lead questions were arranged from general topics (e.g., "Could you please tell me about a time in the recent past when you identified that either yourself or a colleague was nearing the edge of your performance?") to more specific questions (e.g., "To what extent are the indicators you've specified common between controllers?"). This format was selected to lead participants through the topics in a logical progression (Millward, 2006). The interview was recorded on two Olympus DSS standard digital recorders.

26.2.4 Procedure

The participant was welcomed to the interview room and provided with a standardized brief. The participant was then asked to sign an informed consent form if he/she was happy to continue, and completed a demographic questionnaire. The interview began with an open question, followed by several probes. Once the interview was complete, the participant was thanked for his/her time and given a standardized debrief that contained the researcher's contact details.

26.2.5 Strategy of Analysis

Interviews were transcribed orthographically. The level of detail resulting from orthographic transcription was sufficient for the aims of the research and the method of analysis. Only the words that were spoken were captured in the transcription. False starts or self-corrections were included, but no paralinguistic features were captured (such as sighing, intonation) (Strauss and Cobin, 1990; Wilkinson, 2003). Thematic analysis was selected as the analysis strategy (Strauss and Cobin, 1990). In line with the thematic analysis procedure (Strauss and Cobin, 1990; Wilkinson, 2003), the transcripts were read through, and elements of participant responses that were related to the aims of the study were identified. The transcripts were then reread with the aim of categorizing the identified elements into emerging themes. No identifying information was stored in the transcription. Where quotations are used, participants remain anonymous.

26.3 Semistructured Interviews: Results

26.3.1 Controllers' Understanding and Use of Indicators of Potential Performance Decline: Does the Concept of "Performance Indicators" Have Face Validity with Controllers?

All participants (22/22) were familiar with the concept of indicators and confirmed that indicators occurred in the ATC operations room. In general, participants characterized indicators as a sign that a controller was not feeling comfortable with the control task. All controllers stated that indicators are commonly used in ATC to provide information regarding when a controller may not be controlling optimally, or a factor (such as fatigue or stress) is negatively influencing the performance. Indicators also provided information about when a controller was moving toward the edge of performance: *"The indicators are part of losing the control or going towards the limits or crossing the limits [of performance]." (Participant 21).* All controllers monitor their own personal indicators as well as colleagues' indicators: *"… We work close together, we monitor each other, you would be very aware of the person sitting beside you whether they're on the ball or whether they're slightly less, whether they're tired, whether they're distracted by whatever, it's part of the job, and you make allowances" (Participant 2).* This was perceived as a natural process that *"you don't think about … I just do it like it's a brain process that isn't conscious" (Participant 2).* Another controller stated *"I think it's a natural thing to look for signs" (Participant 11).* Controllers used indicators for the primary functions of gaining information that subsequently led to supporting own, or colleagues', performance.

26.3.2 Categorization of Indicators Used by ATCOs: How Do Controllers Conceptualize Indicators?

The participants distinguished between *internal*, subjectively experienced indicators and *external*, observable indicators. Figure 26.1 provides an initial broad categorization of indicators based on qualitative data from controllers. It should be noted that the categories are not mutually exclusive. An indicator can be both experienced internally and also overtly reflected in performance, such as a feeling of being "slow" and falling behind with traffic.

Internal indicators may alert the controller to a specific state or a negative influence on performance: "*I know that when I start thinking, 'Oh it's going fine', I've learned that I force myself to tighten the bolts and to really pay extra attention*" (*Participant 1*). Another said that they change their control strategy "*when I start getting a little bit nervous*" (*Participant 2*).

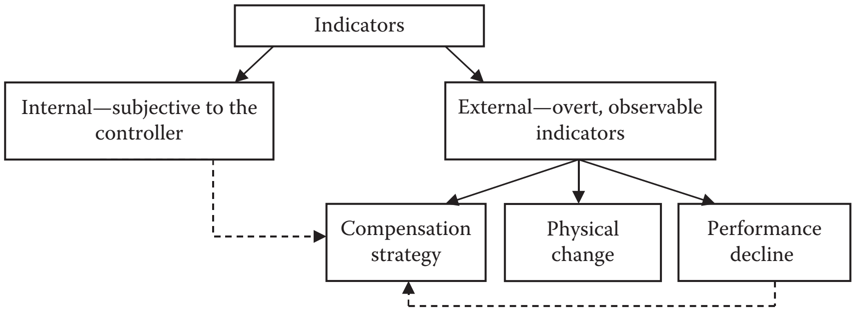

FIGURE 26.1
Categorization of indicators produced from qualitative data internal indicators.

26.3.2.1 External Indicators

In contrast, external indicators are overt and observable. Three broad subcategories of external indicators emerged from participant responses (Figure 26.1). Examples of external indicators that the controllers identified in the interviews are underlined throughout this section. Changes to a controller's performance, such as a performance decline, serve as an external marker to the controller and their colleagues that the controller may not be comfortable. One participant explained: *"When people are controlling you expect a specific performance meaning that they are not going to give too many unnecessary clearances to the aircraft…if you have people doing this, giving an alternative level for no reason then you just start to wonder, 'Why is he doing this?' Okay, he does it once. He was not paying attention on this one. He does it twice and then you start wondering, 'Well it's not his day'" (Participant 1).* Another subcategory of an external indicator is behavioral and physical changes in a controller. Examples include a face becoming red, or fidgeting, and these provide information to other controllers: *"You see it coming, you see them getting nervous, you see them talking faster" (Participant 2).*

Adaptive changes to the control strategy to mitigate negative influences on performance were also identified as a subcategory of external indicators. Employing compensation strategies provides information that a controller is feeling uncomfortable, but is aware of the present situation, and is attempting to protect and maintain the performance. As one controller summarized *"When somebody is just extra careful, I suppose that it's because they feel that they have to be extra careful" (Participant 1).*

If a controller is aware of the present internal indicators, then, a compensation strategy may be selected and applied. This is represented in Figure 26.1 by an arrow with a dashed line connecting the internal marker to the compensation strategy. This is then observable in the method of controlling. Alternatively, a decline in performance may alert the controller that a compensation strategy is required to protect performance. This is represented by an arrow with a dashed line connecting performance decline and compensation strategy. In addition, colleagues may observe the controller's performance decline and apply their own compensation strategy to support the controller's performance.

26.3.3 Subcategories of External Indicators May Provide Distinct Information: Where Are the "Hard Edges"?

Performance declines or errors may provide a more serious indication that a controller is experiencing difficulties with the task. Controllers appear to place weight on this category of an indicator and provide support in response to these indicators: *"If I see that someone is correcting themselves very often then I would pay a lot of attention to what he's actually doing…I really follow every single clearance. I will try to focus more on what my controller is doing and try to support as well like giving hints" (Participant 11).* A physical change (e.g., red face, yawning, and laid-back posture) may indicate a change in controllers' cognitive state (Sharples et al., 2012), although it may not be related to the feelings of discomfort. Controllers suggested that the meanings of indicators are dependent on the context. Adaptive changes in the control strategy inform colleagues that the executive controller (EC) (also known as the "tactical" controller) is experiencing discomfort with the control task (the reason for discomfort may not be observable), although the EC is aware of this and is attempting to protect and maintain performance with the application of a compensation strategy.

26.3.4 External Indicators May Mean Different Things Depending on Context: Do Controllers Moderate the Importance of the Indicators According to What Is Going On?

Indicators may mean different things to controllers also depending on the control context. Participant 1 suggested: *As a coordinator controller you follow what the executive is doing and there is a variety of complexity levels for situations and if it's an easy situation, a very crystal clear solution to a problem and then you see that the person is not applying it straightaway it triggers maybe a little alarm in your head*. This may have been interpreted differently during a high taskload. Controllers use experience and knowledge of the control situation to interpret the meaning of the indicator.

26.3.5 Indicators of Specific Factor Influences: Which Human Factors, and the Associated Indicators, Are the "Usual Suspects" for Controllers?

Participants were asked to identify internal or external indicators that they believed to be associated with a specific influencing factor (workload, stress, and SA). All participants naturally reported adaptive compensation strategies that were applied in response to the detection of a potential performance decline, listed below as one category of an external indicator.

26.3.6 Workload

When talking about workload as a potential influence on performance, controllers differentiated between high workload, low workload, and transitions between workload extremes. Each form of workload was reported to be associated with different indicators.

26.3.6.1 High Workload

Participants reported internal (Table 26.1) and external (Table 26.2) indicators of potential performance decline that were associated with high workload. The findings were grouped into categories, developed from controllers' responses. Changes to the subjective feelings and performance were reported as important indicators that a controller may be reaching the edge of performance: *"If you start to miss the things that you should be doing at certain times, it gets exponentially busier and then you can't catch up anymore" (Participant 4)*. In comparison, physiological change and visible cues indicators were not interpreted to indicate that a

TABLE 26.1

Indicators Internal to the Controller

Proposed Category	Marker
Cognitive changes	Don't know the next steps
	Increased focus
	Calls are a surprise
	Reduced self-awareness
Changes to control	Reactive
	No back-up plan
	No space for an unexpected event/ working to capacity
	Future plan reduces in minutes
Physiological changes	Heartbeat is faster
	Sweat
	Red cheeks
Subjective feeling	Feeling of losing control
	More traffic than can handle
	Panic and uncertainty
	Not comfortable

controller was reaching the edge of performance or that a potential performance decline was likely.

Controllers reported using specific compensation strategies in high taskload periods if they were aware of the potential performance decline (Table 26.3). These were primarily control strategies such as reducing the efficiency to ensure safety, or going "back to basics" to ensure that all aircraft are safe. Several respondents reported that ECs became less self-aware under periods of high workload and therefore more reliant on the coordinating controller (CC) to apply compensation strategies: *"They start to swim… the planner next to them is very much paying attention and they tell them 'Okay now you do this, now you do this, now you do this'" (Participant 14)*. Knowing that a high-taskload phase is coming, and the preparation for a high taskload was reported to be the most effective strategy.

TABLE 26.2

Observed Indicators

Proposed Category	Marker
Perception changes	Executive doesn't hear colleagues
Visible cues	Fidgety
	Move closer to the screen
	Colleagues not talking to one another
Changes to voice	Talking faster/more "say again"s (from pilots)
	Tone of voice
Performance changes	Miss actions
	Mixing call signs
	Can't see a simple solution
	Overlook an aircraft

TABLE 26.3

Compensation Strategies That Were Also Identified as Indicators

Category	Compensation Strategy
Control strategy	Less prioritization on efficiency and more on safety
	Back to basics
	Defensive controlling
	Keep talking so that pilots cannot interrupt
	Quicker decisions but less considered
Verbal changes	No pleasantries
	Speak slowly
Support from CC	Seek guidance from CC
Increase the field of awareness	Sitting back

26.3.6.2 Low Workload

Tables 26.4 through 26.6 list the internal, external, and compensation strategy indicators of reaching the edge of performance during low workload. In comparison to high workload, the indicators reflect the influences on performance through potential boredom or relaxation, leading to distraction: *"In low workload, there's nothing to do so you start doing other things, boredom becomes an issue and then you start talking or having a chat or doing whatever*

TABLE 26.4

Indicators Internal to the Controller

Proposed Category	Marker
Cognitive changes	Pay less attention
	Easily distracted
	Reduced awareness
	Reduced self-awareness
Changes to control	Leave situations to develop for longer
	Trying to create more complex situations
	Less safety buffer
Subjective feeling	Boredom
	Relaxed

TABLE 26.5

Observed Indicators

Proposed Category	Marker
Perception changes	Incorrect assessment of a situation
Visible cues	Sit back on a chair
	Away from the radar screen
	Talking to a colleague
Performance changes	Overlooking an aircraft
	Forgetting an aircraft
	Repeated "sloppy" mistakes
	Fall behind traffic due to distraction

TABLE 26.6

Compensation Strategies Which Are Also Indicators

Repeatedly Check Situation
Sitting forward in low-workload periods: trying to concentrate on the problem

and it's, yeah, you can miss things" (Participant 10). Interestingly, controllers reported leaving a problem to develop for longer or creating complex situations to reduce the boredom during periods of low workload, which could ultimately create a potential uncomfortable situation. This result demonstrates that it is essential to capture the context in parallel with an indicator of performance decline, to ensure an appropriate interpretation.

26.3.6.3 Workload Transitions: When Controllers Need to Shift Gear

The transitions between taskload extremes (low–high and high–low) were associated with specific indicators (Tables 26.7 through 26.9). The indicators were different depending on the direction of transition. A transition from low-to-high taskload required controllers to change their "state" to meet the speed and demands of the traffic, known as a *"gear shift"*

TABLE 26.7

Indicators Internal to the Controller

Potential Category	Marker	Transition Direction
Cognitive changes	Fall behind	Low–high
	No plan	Low–high
	Lack of awareness	Low–high
	Gear shift	Low–high
Subjective feeling	Relax	High–low
	Tiredness	High–low

TABLE 26.8

Observed Indicators

Potential Category	Marker	Transition Direction
Performance changes	Overlooking an aircraft	Low–high High–low

TABLE 26.9

Compensation Strategies Also as Indicators

Potential Category	Marker	Transition Direction
Change in control style	Lower complexity in preparation	Low–high
	"Relax" between busy periods	High–low
Subjective experience	More effort to concentrate	High–low
	Conscious internal reminder to focus	High–low

(Participant 4). Indicators that controllers may not be performing optimally during this transition included falling behind the traffic and losing awareness. Indicators associated with high-to-low taskload transitions were mostly characterized as emerging from a feeling of relaxation after the traffic peak and a resulting loss of concentration: *"… The edge of your performance, that's probably the reason why things go wrong, just after a busy period because people start relaxing and the adrenalin goes away and you lose your concentration" (Participant 16)*.

Several distinct types of performance decline are associated with workload, such as an overlooking aircraft (vigilance issues) and mixing call signs (communication issues). Factors do not occur in isolation, but instead can co-occur, and interact, to produce a cumulative impact on performance (Edwards et al., 2012). For example, workload may negatively influence other factors such as vigilance, fatigue, and awareness that are then observed to be a causal factor of performance decline. This is an important finding for understanding the underlying causes of performance decline that may manifest as a result of a different factor.

26.3.7 Stress

Although respondents differentiated between stress resulting from personal situations and task-related stress, participants reported that both negatively influence performance, and suggested that the indicators and influences of stress on performance were the same regardless of the cause. Respondents also differentiated between "positive" stress and stress that results in a negative experience. Participant 11 explained: *"It's almost excited because there is more traffic coming. It's a different situation if someone is already in a complex situation, you realise he is falling behind then it's a different impression you get from the person."*

Only indicators of stress that influenced controllers negatively were discussed. Respondents emphasized the changes in a subjective feeling, such as feeling tense, uncomfortable, and anxious, as the unambiguous indicators of stress (Table 26.10). This suggests that stress may affect the subjective experience and the associated cognitive changes rather than performance directly. Several observable indicators (Table 26.11) were the manifestations of emotional responses, such as frustration and demonstrations of anger, and the associated physiological changes such as vocal changes, shaking, and fidgeting. Compensation strategies (Table 26.12) were designed to counteract the influences of stress on the controller, such as emotion regulation and practical strategies such as reducing the rate of speech. Support was sought from the CC to further protect performance.

TABLE 26.10

Indicators Internal to the Controller (Negative Stress)

Proposed Category	Marker
Cognitive changes	Start to think slower
Physiological changes	Heartbeat
	Sweat
Subjective feeling	Not coping
	Feeling of doing badly/ uncomfortable (negative)
	Anxious (negative)
	Nervous
	Tense

TABLE 26.11

Observable Indicators

Proposed Category	Marker
Visible cues	Fidgeting
	Red cheeks/neck, flushed
	Sit closer to the screen
Changes to voice	Speaks faster (negative)
	Speaks higher (negative)
	Speaks louder/quieter than usual
Demeanor	Easily frustrated
	Angry/confrontational
Verbal cues	Ask to open a sector
	Communication changes
	Shouting

TABLE 26.12

Compensation Strategies Also as Indicators

Proposed Category	Compensation Strategy
Verbal changes	Speak slower
	More authoritative in instruction
Support from CC	Pay more attention to EC's actions
Emotion regulation	Reduce stress
	Sit back, reduce the anxiety
	Relax

26.3.8 Situation Awareness

Controllers referred to a decline or loss of SA as "losing the picture." The loss of SA was reported to be progressive and occurs in stages that were associated with different indicators: *"It starts off by just falling behind a bit. So you might just be a few steps behind what you're supposed to be doing and if that builds up too much then you will get to the point where you start to lose the picture" (Participant 20).* Therefore, below, indicators of a controller losing the picture, or having lost the picture, are differentiated (Tables 26.13 through 26.16).

The decline of SA was reported to be influenced by the presence of a high or low task demand. The progressive decline of SA was only reported under the conditions of a high taskload. In low traffic, the loss of awareness was more instantaneous: *"We sort of relaxed,*

TABLE 26.13

Indicators Internal to the Controller When Losing the Picture

Proposed Category	Marker
Cognitive changes	Difficulty in selecting priorities
	Thinking while giving the clearance
	Tunnel vision/hearing
Subjective feeling	Underconfident

TABLE 26.14

Indicators Internal to the Controller Having Lost the Picture

Proposed Category	Marker
Cognitive changes	Everything as a surprise
	No plan
	Cannot see a solution
Changes to control	Reactive control
Subjective feeling	Panic

TABLE 26.15

Observable Indicators of Losing the Picture

Proposed Category	Marker
Visible cues	Slow at the task
Performance changes	Running behind
	Time working ahead degrades
	Missing calls

TABLE 26.16

Observable Indicators of Having Lost the Picture

Proposed Category	Marker
Visible cues	Zig-zagging head movement of where to look
	"Blacked out"/silent
Verbal cues	Asking for confirmation
Performance changes	Unsafe clearance
	Unexpected decisions
	Jumping from one aircraft to another
	Don't know who's calling
	Don't react correctly

'Oh, it's done now,' eating a sandwich and the fourth [aircraft] both of us had forgotten about it or not assessed it, but suddenly it's flashing and we're, 'How did we miss that?'" (Participant 4). Controllers felt that the recovery of SA was easier in periods of low traffic as compared to high traffic.

Compensation strategies (Table 26.17) protect performance when a controller is losing the picture. It was reported to be difficult to rebuild awareness after losing the picture. The compensation strategies from the EC primarily attempt to make the situation safe when awareness is degraded. Compensation strategies by the CC are tactical and appear to facilitate the EC in rebuilding the picture. For example, CCs will change the control strategy to reduce the complexity and/or traffic frequency to allow the EC to catch up and rebuild the picture. In addition, CCs will monitor the EC's instructions and step in if necessary until the EC has recovered the picture *"They [CC] tell them 'Okay now you do this, now you do this, now you do this'" (Participant 14).* The more degraded awareness is, the more reliant the EC may be on the CC to protect performance and rebuild the picture.

TABLE 26.17
Compensation Strategies Also as Indicators

Proposed Category	Compensation Strategy
Control strategy	Build the plan as go
	Conservative clearances
	Reduce the complexity
Prevention	Prevention—freeing up space
Support from CC	Get CC to decrease traffic load to allow to build up the picture again—to catch up
	CC to monitor controllers' actions
	CC provides instructions

26.3.8.1 Progression to the Edge of Performance: A Slippery Slope?

Progression to the edge of performance was spoken about in terms of "stages" and the associated experiences. Figure 26.2 provides a representation of the controllers' experience at each stage, developed from participant responses.

Performance is first represented as an uneven line; there will often be minor changes in performance although the overall performance is maintained to a consistently high standard. Within the region of safe performance, controllers experience nominal situations daily that are addressed with relative comfort. Performance is maintained. If demand increases, then, the controller may experience a subjective discomfort with the task. However, respondents suggested that these experiences are seen as "part of the job" and something that all controllers should deal with. Although experiencing a subjective

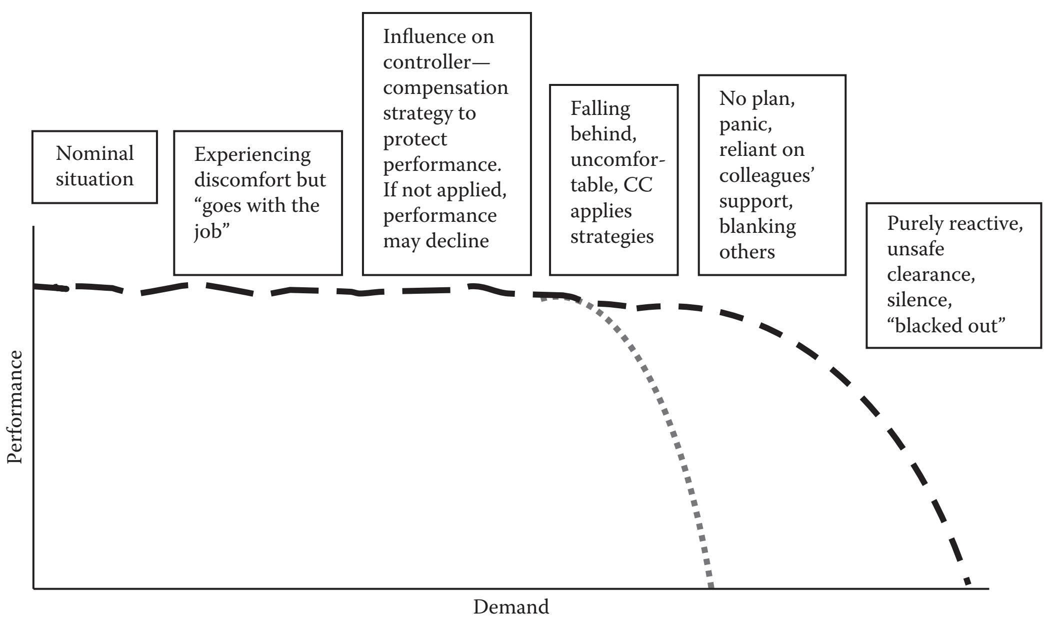

FIGURE 26.2
Diagram of performance and demand with associated indicators and controllers' subjective experience.

discomfort, controllers still complete the control task with a high level of performance. If demand increases further, then, performance may begin to be negatively affected by factor influences such as workload and fatigue. Here, performance may decline. Alternatively, if the controller identifies the threat to performance, then, a compensation strategy can be applied and performance can be maintained. The compensation strategy may not be sufficient to protect and maintain performance if task demands increase. The controller may begin to fall behind the traffic: *"It's something that will build up and you miss one…and then okay maybe you miss another one or two or you're confused as to who called you. Sometimes that happens and it'll go back down again and there's no problems and sometimes it will keep rising, starting to lose the picture" (Participant 2).* Control may become reactive and controllers may rely on colleagues' support for the maintenance of performance. If task demands are reduced, then, it is possible that performance can be recovered. However, if demand is not reduced at this point, then, the so-called "edge of performance" may be reached. Control becomes reactive, and controllers may experience panic. Unsafe clearances may be given. Severe negative reactions may occur, such as a controller shaking or becoming silent. The controller has reached performance limits and is operating outside of safe performance.

26.3.8.2 Awareness of Indicators

26.3.8.2.1 Compensation Strategies Are Dependent on Awareness

Controllers emphasized that the awareness of indicators was critical to employing a compensation strategy. One participant summarized: *"I'd say 300%, if you know that you're not being top performing today then that's fine, just adapt your working style and you'll get through the day. It doesn't really matter but if you don't know it and you're still trying to do the same then it might end in tears" (Participant 12).*

Performance may be protected by several "barriers" (created from awareness and compensation strategies) before becoming vulnerable to factor influences. If a controller becomes uncomfortable with the control task, then, internal indicators such as feelings of discomfort may alert the EC and trigger the application of a compensation strategy. Performance may then be maintained. If an internal marker did not occur or was not detected, then, another opportunity to detect the issue may occur through observable indicators. For example, *"It's getting busy … you start speaking fast and then somebody says 'Say again' and then that's it, you have a hint. 'Okay good, I have to slow down because I was not aware that I was speeding up my transitions because of the amount of traffic'. You slow down and everything's fine again" (Participant 1).* However, if the EC is not aware of indicators, then, the protection of performance is dependent on a colleague's (i.e., the CC's) awareness: *"You're not aware that you're working to the edge of your performance then you need to rely on other people to tell you or people to remind you of how you are working" (Participant 15).* If neither controller notices an issue, then, the participants suggested that performance is more likely to decline than if a compensation strategy was applied.

26.3.8.2.2 Individual Differences in Awareness and Observable Indicators: Same Indicators, Different Reactions

Participants differed in the extent of a conscious awareness of personal indicators. A minority of controllers (3/22) suggested that they personally "sense" or "just know" when they are reaching a performance limit but found it difficult to identify and describe the specific indicators. Overall, there was a consensus that, in general, indicators were generic and common between controllers. However, some indicators appeared to depend on the individual. For example, a change in voice pitch was seen as a general indication that a controller may be finding a situation difficult, but whether the pitch rose or fell would depend on the individual.

26.3.8.3 Indicators Are Learned through Experience: Learning the Hard Way?

Indicators of potential performance decline are not formally taught but are learned through experience. One respondent explained *"You start to know that you've been burning your fingers before on this kind of situation that you really have to pay attention" (Participant 1).* This has implications for trainees and newly qualified controllers. Respondents suggested that inexperienced controllers will be more vulnerable to performance decline as *"they don't know how to protect themselves" (Participant 18).*

26.4 Discussion and Conclusion

An expert opinion regarding the indicators of potential performance decline was generated by conducting 1 hour face-to-face interviews with 22 en-route controllers from MUAC. The interviews were orthographically transcribed and analyzed using thematic analysis. The results revealed that indicators were used in an ATC setting by all respondents, as an indication of when a controller was reaching the edge of performance, or a factor was negatively influencing performance. It was considered as a natural process that all controllers were used. Participants differentiated between internal indicators, representing a subjective experience, and external indicators, which were observable. Three subcategories of external indicators were identified: the changes in performance, physical signs, and application of a compensation strategy.

Participants confirmed that specific factor influences on performance were associated with specific internal and external indicators. Indicators were identified for the factors of workload, fatigue, stress, vigilance, SA, communications, and teamwork. Participants also reported adaptive changes in the control strategy that were applied to maintain performance when the influencing factor was present that resulted from the identification of indicators. This finding builds on previous research investigating controller control strategies (e.g., Kontogiannis and Malakis, 2013), by identifying different control strategies that are applied to compensate for differing performance-influencing factors or situations. Compensation strategies are an integral aspect of the use of indicators in ATC. In addition, compensation strategies were also identified to be used as external indicators themselves of controller discomfort.

The finding that controllers have, and use, indicators of when they are reaching the edge of performance, has implications for the design of dynamic automation systems. If these indicators could be measured online, it may be that tasks could be allocated between the controller and the automation depending on the needs of the controller at the time. In addition, these findings may have implications for the development and application of an observation methodology for controllers in a live operational environment. Further research will need to investigate the generalizability and validity of the identified indicators as an observation method.

Specific factors influenced performance differentially, which in turn influenced the associated indicators. The factors of workload and stress can influence other factors (e.g., communications, teamwork, SA, and vigilance) and the subsequent association with performance. The influences of workload and stress may not be visible in performance but manifest as other factor influences, such as an overlooking aircraft (a vigilance issue) due to fatigue. It is therefore important for aviation professionals to acknowledge the underlying issues of performance declines to gain a valid and comprehensive understanding about factor influences and to understand how to best protect performance. Factors such as SA influence performance directly.

A progression to the edge of performance was developed based on participant responses. The representation describes the subjective experience of controllers at each stage, and the indicators associated with the edge, and moving over the edge of performance. Although this may not be applicable in all control situations, the representation of a move to the edge of performance may provide a standardized understanding of the indicators and control situations to monitor and contributes an understanding to the wider human performance field.

Awareness emerged as an integral element in the use of indicators; controllers needed to be aware of their own or their colleagues' indicators to apply a compensation strategy. It was suggested that there were individual differences in the overall levels of awareness. In addition, controllers suggested that it was harder to be self-aware than be aware of colleagues' indicators. This was especially true for inexperienced controllers who were perceived to not have the experience to identify indicators and apply adaptive strategies. The implication of this finding is that controllers may benefit from an awareness of an initial standardized list of generic indicators. An initial knowledge of generic indicators may especially support less-experienced controllers, or controllers who work on an individual shift system—and therefore do not see their teammates regularly—while building colleague-specific knowledge. Workshops that provide standardized indicators to monitor, and support the development of the awareness of indicators for the self and colleagues, may support controllers in protecting and maintaining performance in the presence of negative influences. This may also support trainees in protecting performance while developing the required experience to identify their own indicators.

Further research may confirm the stages of progression toward the edge of performance and investigate the validity and reliability in generalization to other control centers. In addition, further research may investigate the use of standardized indicators in facilitating supervisors and controllers in identifying the potential performance decline and subsequently applying compensation strategies to prevent the performance decline. Further research should also investigate the feasibility of utilizing the identified indicators during live operations to inform the optimal dynamic allocation of control tasks, with an ultimate goal to support the controller in maintaining a high level of human performance, and preventing performance-related incidents. Finally, the utility of the human performance envelope concept for other similar tasks should be explored. Such work is now ongoing, via the European Commission-funded Future Sky Safety* program of work, which is investigating the applicability of the human performance envelope, along with indicators, edges, and compensation strategies, for airline pilots.

* Project P6 of Future Sky Safety aims to define the human performance envelope for cockpit operations, and identify the methods to recover crew's performance: https://www.futuresky-safety.eu/project-6/

References

Amalberti, R., and Wioland, L. 1997. Human error in aviation. In H. M. Soekkha (Ed.) *Aviation Safety* (pp. 91–108). The Netherlands: VSP BV.

Cox-Fuenzalida, L. E. 2007. Effect of workload history on task performance. *Human Factors*, 49(2), 277–291.

Edwards, T., Sharples, S., Wilson, J. R., and Kirwan, B. 2012. Multifactor combinations and associations with performance in an air traffic control simulation. *Proceedings of the 4th AHFE International Conference*, July 21–25th, San Francisco: USA.

Edwards, T., Sharples, S., Wilson, J. R., Kirwan, B., and Shorrock, S. T. 2010. Towards a multifactorial human performance envelope model in air traffic control. Presented at the *Eurocontrol/FAA Research and Development Conference*, October 19th–20th, Brétigny-sur-Orge: France.

Endsley, M. R., and Rodgers, M. D. 1994. Situation awareness information requirements analysis for en route air traffic control. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 38, No. 1, pp. 71–75). Santa Monica, CA: Human Factors and Ergonomics Society.

Kontogiannis, T., and Malakis, S. 2013. Strategies in coping with complexity: Development of a behavioural marker system for air traffic controllers. *Safety Science*, 57, 27–34.

Mackieh, A., and Cilingir, C. 1998. Effects of performance shaping factors on human error. *International Journal of Industrial Ergonomics*, 22, 285–292.

Millward, L. J. 2006. Focus groups. In G. M. Breakwell, S. Hammond, C. Fife-Schaw, and J. A. Smith (Eds.) *Research Methods in Psychology* (3rd Ed.). UK: Sage Publications.

Park, K. S., and Jung, K. T. 1996. Considering performance shaping factors in situation-specific human error probabilities. *International Journal of Industrial Ergonomics*, 18, 325–331.

Sharples, S., Edwards, T., and Balfe, N. 2012. Inferring cognitive state from observed interaction. *Proceedings of the 4th AHFE International Conference*, July 21–25th, San Francisco: USA.

Sperandio, J. C. 1971. Variation of operator's strategies and regulating effects on workload. *Ergonomics*, 14(5), 571–577.

Strauss, A., and Corbin, J. 1990. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: Sage Publications.

Wickens, C. D., Mabor, A. S., and McGee, J. P. 1997. *Flight to the Future: Human Factors in Air Traffic Control*. Washington, DC: National Academy Press, 14(5), 571–577.

Wilkinson, S. 2003. Focus groups. In J. A. Smith (Ed.) *Qualitative Psychology: A Practical Guide to Research Methods* (pp. 184–204). London: Sage.