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Air Traffic Control automation: for humans or people?

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Introduction

Are air traffic controllers humans or people? At first sight, this seems a very odd question, given that 'humans' and 'people' are near-synonyms in the dictionary and everyday usage. However, in research on air traffic control (ATC) automation the phrase 'human-centred' is used to mean particular aspects of people: for example, it does not usually address their motivations for embracing change or cover organisational behaviour issues. The objective here is to try to understand how the fact that air traffic controllers are people – particular kinds of people – is likely to affect the introduction of automation. This examination takes as an example a suite of computer assistance tools for en route ATC. How would these tools need to change if the fact that controllers are 'people' is taken into account?

Some definitions and background references are necessary for the following text. For simplicity, definitions and explanations of technical terms will be those in 'The Future of Air Traffic Control: Human Operators and Automation' (CBASSE, 1998). This is an invaluable reference source, especially because it is available in browsable Open Book format. One key definition is that of 'automation':

> *a device or system that accomplishes (partially or fully) a function that was previously carried out (partially or fully) by a human operator.*

This is a very broad statement: it covers both the introduction of computer technology where it did not exist before and computer systems that possess some

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degree of autonomy. Automation in the context of engineering psychology is reviewed by Wickens and Hollands (2000). A very valuable European Commission project on ATC automation was RHEA – the 'Role of the Human in the Evolution of ATM Systems' (Nijhuis, 2000).

The suite of computer assistance tools used to illustrate points is a subset of those being developed through the Eurocontrol Organisation (Kauppinen (2003) provides a brief description of the 'ASA Tools' programme of work). There are some excellent review and research papers on these tools published by staff of Eurocontrol's Experimental Centre. These include Hilburn and Flynn (2001); Kirwan (2001); Kirwan and Flynn (2002a); Kirwan and Flynn (2002); Pichancourt and McGregor (2001).

Important research papers on these kinds of computer tools and automation generally – a selection from a much larger number – are Farmer (2002): Leroux (1997); Magill (1997); Pavet (2000); Printemps (2001); Swierstra and Green (2003); Whysall (1998); and Wilson (2000).

There is an extensive literature on 'function allocation': selecting the right type and level of automation, in particular deciding how to allocate tasks between operators and automation. Fitts (1951) is the key early reference – note that the topic was the ATC system! Bainbridge (1983) is a justifiably frequently quoted paper. A whole issue (2000 (52), part 2) of the International Journal of Human-Computer Studies was devoted to the topic, of which the paper by Sheridan (2000) is probably the most relevant here. The concept of human-centred automation mainly originated in Billings (1991).

Research on people's motivation and the nature of job satisfaction tends to be found in the (huge) organisational management literature. A good general source is Mullins (2002), which *inter alia* refers to work by Maslow (on the hierarchy of needs), Alderfer (ERG theory), Herzberg (motivation and performance), Vroom and colleagues (Expectancy theory), and Hackman and Oldham (meaningfulness/job enrichment). Mullins does not cover all the potential research of interest here: an example is the work by Bruggemann and her colleagues (1974 and 1976) on different kinds of work (or job) satisfaction [Bruggemann's work does not appear to be in English translation, but its main points are summarised in the very useful notes by Lauche (2002)]. Kohler (1997) provides a history of team working experiments and developments. Buchanan (2005) summarises recent USA work on employees' 'engagement'. Costa (1995) reviews the sources and consequences of stress in air traffic control.

Psychological studies on occupational interests and personality types are most frequently encountered as commercial products. An example is the Louisiana Integrated Skills Assessment (2005). Original sources for these tests include Holland (1985) and Kuder (1977).

There are extensive quotes from this literature in the following. Spellings have been changed to UK English and obvious typing errors corrected. References identified in quotes are those given in the original source material.

The computer assistance tools example

A Eurocontrol programme of research and development into operational concept using controller tools is currently in progress (Eurocontrol, 2005). From the published literature, it is probably the most comprehensive programme world-wide on this topic. The programme is entitled ASA: Automated Support to Air Traffic Management (ATM). A subset of the tools is used here to illustrate the points being made. This subset leads up to and includes the Conflict Resolution Assistant (CORA), which aims to provide a support tool to en route controllers (i.e. away from airport operations) in the area of conflict resolution. This suite of 'CORA Tools' is sketched in Kauppinen (2003).

A key element must be the *detection* of potential conflicts. These occur when flightpaths – used here to mean the entire space and time representation of a flight – come into conflict. Thus, at the heart of this process must be some prediction of the flightpath, a basis for the user tools. The tools that lead up to CORA are:

- *TP* (Trajectory Predictor) predicts the routes of the aircraft and hence determines, within accuracy and uncertainty bounds, the likely conflict regions and conflicting aircraft. [The accuracy of MTCD below, and ultimately the usefulness of CORA, depends critically on the performance of TP.]
- *MONA* (Monitoring Aid) checks for non-conformances of aircraft after they have received instructions (e.g. a heading or altitude change) or other deviations from their intended flight routing.
- *MTCD* (Medium Term Conflict Detection) detects potential conflicts. It is medium term, by which is meant that it looks up to 20 minutes ahead. It detects conflicts between all the aircraft pairs examined. It does *not* provide advice to controllers on what to do about conflicts where they are detected.

The main objective in using the tools is to increase the safe throughput of the ATC system. Thus, the average taskload per aircraft for a controller team has to reduce significantly by the use of the tools (Brooker (2003) provides background and key references on taskload and related ATC topics). It needs be stressed again that tool usage needs – at the very least – to maintain the safety of the ATC system.

These tools are general in nature, i.e. can be adapted for different kinds of airspace structure and controller organisation. For present purposes, the following is assumed (a considerable simplification of the controller team arrangements):

Airspace is divided into sectors. Each has a planning controller (PC) and a tactical controller (TC)

The PC has to coordinate and agree entry and exit of flights into the sector, usually by telephone. PCs try to find the flightpaths, e.g. identify flight levels, that are least likely to generate potential conflicts as the flight progresses.

The TC communicates with the aircrew by radio telephone, accepts the aircraft into the sector, monitors its progress, detects possible conflicts in the sector, issues instructions to eliminate these conflicts, and achieves the exit conditions set by the PC.

Generally, the TC is more highly loaded than the PC. The aims of the ASA toolset are to reduce and rebalance taskload.

How can taskload be reduced? Divide the course of a flight into upstream – earlier times – and downstream – later times. If there is a conflict now downstream, could it have been 'designed out' upstream, i.e. the PC could have detected the potential conflict and made better coordination arrangements? This reduces the TC taskload by removing some elements of conflict detection and resolution taskload.

A variety of CORA tool types could exist, and are the subject of ongoing research. The simplest version is described in Kirwan and Flynn (2002b). The following is an edited version of parts of that report explaining CORA:

CORA builds upon MTCD.

It will offer a set of ranked resolutions to the en route controllers, principally the PC.

The controller may select the highest ranked resolution for implementation, or a lower ranked one if that is judged to be more appropriate. Alternatively, the controller may reject all of the suggested resolutions in favour of a new controller-generated resolution.

CORA is not intended to replace the controller's skill of conflict resolution, but rather is meant to support it and extend the controller's abilities and capacity for handling more traffic safely and expeditiously.

None of the ASA tools or concepts is aimed at replacing the controller. Their role is to enhance the planning ability of ATM, with the controller remaining at the heart of that planning process, albeit assisted by a variety of integrated tools.

This planning focus means a greater 'look ahead' time generally in ATM, and a particular aspect to keep in mind throughout this current review is that the intended 'look-ahead' time for CORA is 10 – 20 minutes (somewhat longer than many current ATM practices). The degree to which current en route controller strategies can be extrapolated to longer look ahead times

> *therefore needs to be examined at some point before using such strategies to generate conflict resolution algorithms.*

The comment in the final paragraph is important from a technical viewpoint of Tools development (Magill, 1997; Swierstra, and Green, 2003). There are errors of various kinds when forward projections are made of an aircraft's flightpath, and these uncertainties limit TP performance and hence that of CORA Tools.

Human-centred automation and CORA tools

The philosophy of human-centred automation is characterized by CBASSE (1998) as including:

> *The choice of what to automate should be guided by the need to compensate for human vulnerabilities and to exploit human strengths.*
>
> *The development of the automated tools should proceed with the active involvement of both users and trained human factors practitioners.*
>
> *The evaluation of such tools should be carried out with human-in-the-loop simulation and careful experimental design.*
>
> *The introduction of these tools into the workplace should proceed gradually, with adequate attention given to user training, to facility differences, and to user requirements.*
>
> *The operational experience from initial introduction should be very carefully monitored, with mechanisms in place to respond rapidly to the lessons learned from the experiences.*

This is a very challenging list. None of the statements is simple (e.g. the complexity of developing simulation trials and understanding their results is discussed in Dubey (2000)).

⇒	Key design driver is capabilities and deficiencies of end user
⇒	Controllers are limited capacity information processors
⇒	Controllers inherently make some mistakes/errors
⇒	Controllers must work *with* other controllers
⇒	Controllers are different
⇒	Controllers cannot easily be changed
⇒	Must fit the person to the job and the job to the person
⇒	Must learn from system failures

Figure 1 Human-centred design recipe components

Human-centred design needs guidelines and rules-of-thumb. Figure 1 shows a list of some of the more obvious components, which are compatible with the CBASSE list.

It is interesting that the word ‘human’ is used here. No normal 21st century manager using UK or USA English idiomatically would speak of a staff or team composed of humans. Grammarians use the word ‘synecdoche’ when a part of something is used to represent the whole. Thus, in 19th century Britain, the people working in a factory would have been called its ‘hands’, a rather cold – demeaning – way of referring to people.

The RHEA work (Nijhuis, 2000) provides a good summary of human factors work on ATC automation (see also Farmer, 2002). It did in fact bring into consideration the kinds of people aspects, such as motivation and job satisfaction, that are of interest here. For example, it rejected some options for automation because operators would be ‘out of control’, and so lose job satisfaction, and that that they would de-skill the controller, and hence put safety at risk if the system fails.

A key issue in the introduction of automated systems was seen to be the level of operator trust. Of the various levels of automation considered, the best option, in the present context of CORA Tools, was one in which the system gave advice for acceptance or rejection by the controller. This was considered to be most workable when the advisory system was consistent with the controller’s own mental model. For the CORA Tools, Kirwan and Flynn (2002) investigated these mental model aspects – the explicit rules that controllers pay attention to, the implicit strategies they adopt when solving conflicts, and the factors that controllers consider when carrying out conflict resolution.)

But note that even this ‘best’ ‘Machine Proposal Strategy’ has both benefits and drawbacks (Nijhuis, 2000):

> *The system suggests ‘solutions’ that the controller may choose to implement or not.*

- *Benefits: save human resources, remains indifferent to traffic load, never fails to consider side-effects of actions, overcomes any narrowing of situation awareness or tunnel-vision*
- *Drawbacks: work overload because of under-confidence in the output of the system, more superficial situation awareness, loss of core skills, loss of flexibility, possible complacency by over-confidence in the output of the system.*

CORA has been developed in ways that *inter alia* attempt to eliminate or reduce the drawbacks identified here. In particular, problems with situational awareness are mitigated by making CORA a tool for use by the PC rather than the TC. The report on the Eurocontrol real-time simulation study (Pichancourt and McGregor, 2001) conclusions section includes the following comments.

> *The most highly commended tools were the DFL (Dynamic Flight Leg), the PAC (Planned Alternative Clearance), and the Interfering Aircraft Filtering function. These tools enhanced traffic situational awareness, assisted the Planning Controller in solving problems earlier, and permitted the optimisation of flights.*
>
> *Participants were agreed on the usefulness of the Medium Term Conflict Detection (MTCD), however they felt the rate of false and missed alerts must be improved.*
>
> *Improvements are required in the quality of trajectory prediction, but also the HMI presented in the Potential Problem Display (PPD) and the Planned Activity Display (PAD).*
>
> *To maintain confidence, the Tactical Controller must continuously crosscheck their problem detection with that of the system. The controllers did not wish to be system driven. The potential risk of over-trust (and a lack of situation awareness building) must be anticipated and managed…*
>
> *Participants identified the risk of controller de-skilling in problem detection as a problem. To a certain extent as the controller is still responsible for resolution design (with the support of the filtering function), the deskilling is potentially reduced. The risk could be that the controllers over-rely on the system and end up system driven…*

Controller concerns about automation

Air traffic controllers are generally in secure jobs with reasonable salaries and pensions. Controllers would not be expected to rush to implement things that would put them out of a job. Nor would they be expected to rush to implement changes that de-skill their role. This obviously colours how they view automation, even human-centred automation. The lengthy training programme for controllers, including the need for validating their skills operationally, means that there are significant 'barriers to entry' in the profession. There is not a simple labour market for en route controllers. In economic jargon, the provision of ATC services and hence controller employment is not readily contestable. As a general rule, controllers cannot be forced into using new skills by the threat of job losses or competition by firms using new technology and practices (compare newspaper publishing's move from 'hot metal' typesetting to the new technology 'cold type' (Encyclopædia Britannica, 2005)).

The kinds of concerns about automation (in the largest sense) voiced by controllers were encapsulated a decade ago in an International Labour Office review by Costa (1995):

> *There is a justifiable concern for increased human boredom, decreased motivation, loss of situational awareness, over-reliance on and misuse of automated systems, and deterioration of skill.…Regarding information processing, it has to be taken into account that the cognitive competence of controllers consists of simultaneously mastering part of the procedure by application and/or adaptation type. For the moment, it is the controllers themselves who 'decide' about this division according to their personality and cognitive structure. With automated workstations, this division will be taken over by the machine, and the controller will then only need to apply or adapt. Some may suffer from this and gain the impression that they can no longer pursue their own logic independently, that they are losing landmarks in their reasoning and that they can no longer think in a reliable manner.*
>
> *…[W]hat is the limit beyond which the controller will have the impression that his powers of decision are being 'stolen' from him? How far can one go in letting him control the process of deciding and not simply 'speaking the right information into the microphone'? The answer to the question is not an easy one, since it is difficult to find the balance between the stress alleviation by increasing the security of the man/machine system, and the reduced involvement which reduces security through a drop of vigilance.*

More recently, the UK's Guild of Air Traffic Control Officers issued a policy statement on automation (GATCO, 2003), with Conclusions as:

It is the case that the impact of automation will cause a change of role and that the change will make it unwise for controllers to continue to accept responsibilities that will become increasingly difficult to fulfil.

The increasing use of controller tools, and the evolution to a task driven role could impair a controllers 'picture' and make a controller increasingly dependent on automation.

System algorithms and logic, designed by scientists and engineers, are often at variance with the mental processes of controllers. Although a machine and a controller may have designed the same solution, the process by which a machine develops its conclusions is not necessarily obvious or logical to a controller. This makes it difficult for a controller to validate the output of automation, even if the controller had time to do so.

Peak traffic levels will be sustainable only with the contribution of automation. In the event of a catastrophic system failure under peak traffic conditions, a controller's ability to provide an effective manual recover will be so limited that an alternative approach should be considered and implemented.

[It is worth noting that the third of these should not be deemed to apply to the Eurocontrol work on CORA, where a considerable amount of effort has been expended by research teams – including controllers – to match 'automation solutions' to those of controllers (Kirwan and Flynn, 2002a/b).]

A very important appreciation of progress in ATC automation in France has been given by Printemps (2001). The French ATC organisation has put considerable investment and resource into this kind of development, so these lessons from French experts have considerable value:

- <u>Main benefit of automation</u> *The average number of flights a controller can handle has not increased, and even has decreased compared to the situation 30 years ago one could ask whether there is any benefit to automation…the main benefit of automation has been to permit a safe increase of the number of sectors, and to permit more complex sector definition and route patterns (it is not only a volume of airspace, but rather a set of possible trajectories and coordination rules). Consequently, it has become possible to handle a much higher traffic.*
- <u>A revolution is no longer possible</u> *The first lesson that emerge from the past experience is that in ATM automation a revolution is no longer possible (unless you accept strong disruptions in air transport). Twice, in France, it*

was attempted to go for a radical change, twice it has been necessary to go back for a smoother transition.

- *Flight data input are kept to the strict minimum Automation up to now has help the controller to filter and get easily the information required to build this mental picture. French controller has been quite demanding in the man machine interface, and in particular the input in the computer that are necessary…It is also recognized that providing advanced automation will require that the computer get access to these data known only by the controller, and that are generally written on the paper strip.*
- *Each automation elementary step must bring in direct benefit Controllers will not appropriate and/or use a functionality that does not bring a direct benefit to them. Of course you can impose them a new function and they may not have any other choice than using it. However the automation strategy should avoid such scenario.*
- *In the field trials are a key to success Since the mid seventies all major new functionalities has been introduced after a long period of real time simulations followed by trials in operational centres using live data…The appropriation of the tools by the controller is a complex process, sometime surprising.*
- *Increase safety first The main objective, as seen by a manager, is to increase capacity at an acceptable cost…But increasing capacity of the control position itself cannot be separated from increasing safety of the work of the controller. Safety and capacity are considered to be the two faces of the same coin. If tools are given to the controller to increase the safety of its working environment, capacity will consequently increase.*

The current French plans for automation focus on the ERATO project – which has similarities to the CORA Tools (see Printemps (2001), Leroux (1997)).

Motivation, organisational behaviour and job satisfaction

A distinction was drawn earlier between ‘humans’ and ‘people’. The key point – and this is probably worth repeating ad nauseam – is that research work on human-centred ATC automation does not generally cover organisational, motivational or job satisfaction aspects. CBASSE (1998) notes:

> *For some in the general public the introduction of automation is synonymous with job elimination and worker displacement. In fact, in popular writing, this view leads to concerns that automation is something to be wary or even fearful of. While we acknowledge that automation can have negative, neutral, or even positive implications for job security and worker morale, these issues are not the focus of this report.*

It is interesting to note the phrases 'general public' and 'popular writing' in this extract: they seem to be used pejoratively. If they are not to be the focus of this – the CBASSE book – then where are they supposed to be dealt with? Later on in the book, there is a paragraph on user acceptance:

> *As with many sophisticated forms of automation, if systems like these are not carefully designed and introduced with adequate concern for controller training, the potential exists for limited user acceptance to threaten job satisfaction, which may in turn be reflected in perceived job insecurity. The more capable such automated systems are, the more likely such fears become. Furthermore, history suggests that such fears are not always unwarranted; in 1982, the FAA's modernization plans were presented to the U.S. Congress with the promise that they would reduce future staffing requirements (Stix, 1994). Some also fear that advanced air traffic control automation, if not well-designed, may erode the job satisfaction a controller derives from resolving a challenging situation (Harwood, 1993).*

Thus, these comments note the relevance of these factors, but do not attempt to address them as an important aspect of psychology in the broadest sense. CBASSE (1998) does also refer to the work of Wiener and Curry (1980 *et seq*) on job dissatisfaction in pilots [to be covered later here]. Note also that Wickens and Hollands (2000) has no entries for motivational or job satisfaction in its index.

The crucial point is that these 'people' aspects are not second order effects, somehow to be 'worked around'. The introduction of automation has to be viewed in a holistic fashion. It is not sufficient to create pieces of automation and expect that these are modules to replace existing processes: the organisation and the nature of the jobs within it have to be redesigned. If this is not done, then the pace of beneficial automation – helping more aircraft to fly safely through currently congested airspace – will be slow. Controllers will be reluctant to use new tools and, even when they are introduced, they may not use them to their full potential. [A quote from a Tools expert: 'great in low level traffic conditions to keep the controllers amused at idle moments, but, as soon as it gets hectic, controllers ignore the Tool because "they have work to do"'.)

The motivation and job satisfaction issues are obvious ones. If the controller is presented with a proposed conflict solution, then where is the skill in just agreeing to it? If the controller's job if just to sit and watch the screen until something peculiar happens, then the job becomes rather tedious. It is one thing learning certain rules and then applying them: it is another thing entirely when one works to a pre-programmed script, having to operate without much freedom or discretion.

Part of the problem is that controllers are people and part is because they tend to be particular kinds of people. People-problems with work motivation and job satisfaction have been studied for many years, e.g. see Mullins (2002). There are many theories and criteria for job design about this aspect of psychology, as noted in the Introduction. Some people criteria that relate to controllers and automation include:

- *Alienation*: the need for a worker to perceive that his or her part of the production process is important.
- *Autonomy*: 'experienced responsibility' – note that controllers generally work in long-standing teams and tend to refer operational decisions upwards to supervisors in exceptional cases, where atypical safety problems need resolution over a wider airspace dimension.
- *Feedback*: 'knowledge of results' – the controller immediately sees that aircraft are moving smoothly through the sector on reasonable flightpaths.
- *Task completeness*: the controller knows and deals with the full problem, and thus can justifiably feel responsible.
- *Process Control*: the controller has a choice about what means to use to solve problems.

The human-centred approach to automation using CORA Tools sketched in the earlier sections certainly makes use these kinds of criteria.

Controllers are particular kinds of people. Controllers need to have specific abilities, e.g. spatial awareness, and as a group tend to show particular occupational interests and preferences – to have a particular personality type or pattern (e.g. Holland (1985) and Kuder (1977)). Occupational psychology may not have the academic prestige of cognitive or engineering psychology, but it has undoubtedly had major effects on vocational planning and employee selection.

It is hardly surprising that controllers need to be stable and dependable individuals, but the collected characteristics of their general personality type are very interesting. From the Louisiana Integrated Skills Assessment (2005):

> *According to Holland's interest theory, Air Traffic Controllers are classified primarily as Conventional. People with Conventional interests like work activities that follow set procedures and routines. They prefer working with data and detail more than with ideas. They prefer work in which there are precise standards rather than work in which you have to judge things by yourself. These people like working where the lines of authority are clear. The second Holland category is Realistic. People with Realistic interests like work activities that include practical, hands-on problems and solutions…*
>
> *The highest Work Values for Air Traffic Controllers include Achievement and Support. The Achievement Work Value is associated with jobs that let workers use their best abilities, see the results of their efforts and get the*

feeling of accomplishment. The Support Work Value is associated with jobs where the company stands behind its workers and where the workers are comfortable with management's style of supervision. These companies typically have a reputation for competent, considerate, and fair management.

Automation does not *per se* damage the characteristics noted in the first paragraph of this extract, but it causes great problems for the Achievement elements in the second paragraph. Controllers see themselves as skilled professionals, and so are very alert to anything that might downgrade their status.

How to make progress?

It would be wrong simply to suppose that controllers are in general intrinsically opposed to automation. As part of the CORA Tools work, Hilburn and Flynn (2001) carried out studies into controller attitudes to automation. To quote two points from their work:

Much of what emerged from these data does not agree with the stereotypical view of the air traffic controller as over-stressed recalcitrant neo-luddite. Indeed, the involved controllers all recognised and respected the need for new forms of ATC automation.

Controller acceptance is likely to be much higher if justifications for change are accompanied by demonstrable benefits, preferably early in the design cycle (e.g. via prototypes). Controllers are generally aware of the need for new systems, if only to handle increasing traffic loads. By and large, the consensus view was simply that they wanted some assurance, in advance of operational use, that new tools would be useful and reliable.

So, given all the research work carried out into ATC automation, what is needed to fill the gaps identified in the previous section in terms of motivation, work satisfaction and controller personality traits? How can people be motivated to embrace changes in operating practices and to use automation tools effectively? What needs to be done for controllers to believe that their Work Values of Achievement and Support are being enhanced? The following sets out some thoughts rather than a set of simple recipes: this is a tough problem to solve.

As already noted, there is an extensive literature of this topic. Mullins (2002) sketches out the main theories of Maslow, Alderfer, Herzberg, Vroom, Hackman and Oldham; while there is ongoing work on the subject, e.g. Bruggemann (1974/1976). The following text highlights some of the most relevant points and theories about peoples' motivation.

Motivation covers a variety of things. From the 'outside', it is a willingness to exert effort to meet particular organisation goals. From the 'inside', it is a need within the person that means that certain work outcomes appear attractive. What are these needs and how do people's needs differ?

Alderfer's simple 'ERG' theory of needs is a simple categorisation into:

- *E*xistence needs – food, shelter, etc
- *R*elatedness needs – good interpersonal relations, open communication, etc
- *G*rowth needs – self-development/creative/productive work

How would a controller's needs be split between these three? In the present context, it hardly matters: the key point is that automation, even of the human-centred CORA Tools variety, deals a blow to the Growth needs.

Would some kind of goal-setting do the trick? By goal-setting is simply meant that individuals are presented with something that compares their present performance with that needed to achieve particular goals. Some of the organisational criteria for goal-setting to work would be met: the CORA Tools package is within the capabilities of controllers; it is feasible to give feedback on performance (e.g. traffic handled, economic flight paths); it is possible to make goals specific. But there is the major problem of acceptance of and commitment to the goal. For example, controllers could certainly be paid more for attaining the goal, but would they judge it to be an achievement; would they believe that they were 'in control' or just 'a cog in the machine'? Given the controllers' Support Work Value, an over-emphasis on reward (and punishment?), or with the process being seen as controlled from the top, would probably be viewed negatively.

Expectancy theory defines three new terms (figure 2), with the belief that high ratings on these factors will result in improved performance.

Process theory about work motivation – focuses on *how* people make choices re behaviours and effort:

- *Valence*: desirability of an outcome to an individual.
- *Instrumentality*: perception about the extent to which performance of one or more behaviours will lead to the attainment of a particular outcome
- *Expectancy*: a perception about the extent to which effort will result in a certain level of performance

Figure 2 Expectancy theory

Bruggemann's work (1974, 1976) is in some ways a development of Expectancy Theory. It focuses on different need levels that may or may not be fulfilled in the current work situation. People's evaluation of the situation will result in satisfaction or dissatisfaction, influenced by the expectancy level. Bruggemann identifies unhealthy organisations when people have a distorted perception of the work situation or where they stop looking for new solutions to problems. This feeds back to the controllers Achievement and Support Work Values.

One possible avenue is to focus on safety. As Printemps noted above: 'If tools are given to the controller to increase the safety of its working environment, capacity will consequently increase'. As noted earlier, the CORA Tools are 'marketed' as increasing capacity by rebalancing workload, but they do in fact do this by helping to filter out for the TC a sizable proportion of potential aircraft conflicts. Has this filtering role received enough attention? As Hilburn and Flynn (2001) note, the value of short term conflict alert warnings is now well established, so could not the safety dimension of CORA Tools be made much more explicit?

One key feature surely has to be for Tools to be seen as requiring expertise in their use, i.e. the controller *gains* an extra skill. Because there is this new skill, the controller should get paid significantly more for using this additional rating/validation (which picks up the earlier comments about goal-setting). Some more pay for controllers is a bargain for airspace users if he/she can deliver real benefits to flights. But the controller has to demonstrate operationally that he/she can handle more traffic, or, that at the same traffic rate as at present, a higher percentage of aircraft get fuel-efficient flight paths.

If this were to be the way forward, then there are some consequences. The Tool has to be of 'interrogation' form: the controller uses his/her initiative to test from a small sub-set of options, *including* seeing their different benefits to flights (compare the Printemps (2001) and Hilburn and Flynn (2001) conclusions re benefits). The Tool has to provide indications to the controller if his/her choice might cause downstream problems or is potentially slightly 'risky' (e.g. if the option's projected flightpaths use something near to the minimum safe separation and so require workload from the TC in ensuring that required separation is maintained). Data entry of changes to flightpath/intent has to be a necessary ingredient of Tool usage – otherwise the system TP projections, and hence everything else in the CORA Tools, will be of poor quality (see Eurocontrol Learning Server, 2005). Thus, for example, the controller would (say) have to click a mouse on the Tools display to confirm that a particular instruction had been issued.

A further strand would be to examine the lessons learned from the introduction of flightdeck automation (e.g. Flight Deck Automation Issues, 2003). These have some positive elements, e.g. to quote CBASSE (1998):

> *The question of job satisfaction in a highly automated environment was first raised by Wiener and Curry (1980). Since then, both authors have stated*

> *that in their field studies they found no trace of automation-induced apathy or job dissatisfaction (Curry, 1985; Wiener, 1985, 1989). If anything, pilots seem to be proud to be flying a modern aircraft and highly satisfied with the job. However, it should be noted that satisfaction with the automation provided by the FMS can vary greatly, depending on the attitude fostered by airline management (McClumpha and James, 1994).*

The word ‘proud’ stands out in this extract. So, the controller has to believe that he or she has ‘moved up a gear’, and not just to believe this as a piece of successful management propaganda but as a valid description of a newly challenging job that delivers a safe product.

Lessons

There is no doubt that excellent work has been done into ATC automation from the viewpoint of engineering psychology. The problem is that this approach may produce comparatively little of practical usage – or perhaps it will just take a very long time for implementation? Progress requires organisational and personality psychological aspects to be incorporated in a holistic exercise.

Aviation has made most of its technological advances by adopting scientific reductionism: breaking the big problems down into smaller, more easily addressed, ‘chunks’ and then solving each these. The modern aviation industry demonstrates the success of this methodology. Psychology has usually followed this approach, looking hard at the cause and effect relationships in the separate chunks. The difficulty here is that the various psychological chunks have not received comparable or consistent attention; nor have they been integrated together.

A metaphor is that of a food manufacturer whose researchers produce a nutritionally efficient packaged meal, but which has a bland taste and cannot be consumed at the same time as alcohol. What would the take-up of such a product be? Abstemious health-orientated individuals would no doubt like it, but the majority of people would not. There would be little incentive for the majority to buy it as long as people had a choice. *If* circumstances were desperate *and* a dictatorial government could impose its consumption, then things would be different – but that is not how people live in the developed world or a good model for changing how controllers work in ATC organisations.

The problems identified here are not new ones. If there is a new problem, it is that past research results are not being fully incorporated into current thinking and research. A striking example is given in Whitfield (1982), which summarises human factors issues arising during eight years of systems research into computer-based concepts (carried out by the Royal Signals and Radar Establishment and

Aston University on behalf of the UK Civil Aviation Authority). Whitfield's Conclusions include:

> *Intrinsic motivation and satisfaction for controllers comes from tasks which provide a challenge, and on which effective performance leads to feelings of competence and achievement.*
>
> *Automation of entire functions, or the provision of computer-aiding with some functions, might be acceptable to controllers if the need was perceived by them and if the overall job still retained a balance of challenging and more routine tasks. Certainly, boredom or lack of satisfaction in some tasks can be compensated by the existence of challenge in others.*

These are as vital now as they were then.

References

Bainbridge, L. (1983). Ironies of Automation. *Automatica*, *19*, 775-779.

Encyclopædia Britannica (2005). *Newspaper publishing: the modern era.* http://www.britannica.com/eb/article?tocId=28677.

Billings, C.S. (1991). Human-centered aircraft automation: a concept and guidelines. *NASA Technical Memorandum 103885.* NASA Ames Research Center, Moffet Field.

Brooker, P. (2003). Control Workload, Airspace Capacity and Future Systems. *Human Factors and Aerospace Safety, 3*, 1-23.

Bruggemann, A. (1974). Zur Unterscheidung verschiedener Formen von 'Arbeitszufriedenheit'. *Arbeit und Leistung, 28*, 281-284.

Bruggemann, A. (1976): Zur empirischen Untersuchung verschiedener Formen von Arbeitszufriedenheit. *Zeitschrift für Arbeitswissenschaft*, *30*, 71-74.

Buchanan, L. (2005). The Things they do for Love. *Harvard Business Review*, August, 19-20.

CBASSE [Commission on Behavioral and Social Sciences and Education] (1998). *The Future of Air Traffic Control: Human Operators and Automation*. C.D. Wickens, A.S. Mavor, R. Parasuraman and J.P. McGee (Eds). National Research Council, National Academy Press, Washington, D.C. http://www.nap.edu/openbook/0309064120/html/R1.html#pagetop

Costa, G. (1995). *Occupational stress and stress prevention in air traffic control*. (CONDI/T/WP.6/1995). International Labour Office, Geneva. http://www.ilo.org/public/english/protection/condtrav/pdf/wc-gc-95.pdf

Dubey, G. (2000). *Social Factors in Air Traffic Control Simulation.* E.E.C. Report No. 348, Eurocontrol Experimental Centre.

http://www.eurocontrol.int/eec/gallery/content/public/documents/EEC_reports/2000/EEC_report_348.pdf

Eurocontrol (2005). *ASA Projects list.* http://www.eurocontrol.int/asa/public/standard_page/ASA_PROJECTS.html

Eurocontrol Learning Server (2005). *TP, MONA and MTCD Learning Aids.* http://elearning.eurocontrol.int/infopacks/tp_mona/01/C58886.html, http://elearning.eurocontrol.int/infopacks/tp_mona/02/index.html

Farmer, E. (2002). The Future of Air Traffic Control. In, C. Weikert (Ed.) *Proceedings of Human Factors and Safety in Aviation Conference, 2002.* Lund; Sweden.

Fitts, P.M. (1951). *Human engineering for an effective air navigation and traffic control system*. Ohio state University Foundation Report, Columbus, Ohio, USA.

Flight Deck Automation Issues (2003). Website. Oregon State University and Research Integrations, Inc. http://www.flightdeckautomation.com/fdai.aspx

GATCO [Guild of Air Traffic Control Officers] (2003). Policy Paper: Automation. 5th September 2003. http://www.gatco.org/policy/automation.html

Hilburn, B. and Flynn, M. (2001). Air Traffic Controller and Management Attitudes Toward Automation: An Empirical Investigation. In , *Proceedings of 4th USA/Europe Air Traffic Management RandD Seminar, Santa Fe.* http://atm2001.eurocontrol.fr/finalpapers/pap152.pdf

Holland, J.L. (1985). *Making vocational choices: A theory of vocational personalities and work environments* (2nd edn.). Englewood Cliffs, NJ: Prentice Hall.

Kauppinen, S. (2003). CORA COnflict Resolution Assistant: Human Factors Lab experiments. *NEXTOR Conference on Air Traffic Management and Control*. http://www.nextor.org/pubs2/Symposium03/CORA-Conflict-Resolution.pdf

Kirwan, B. (2001). The role of the controller in the accelerating industry of air traffic management. *Safety Science, 37*, 151-185.

Kirwan, B. and Flynn, M. (2002a). *Investigating Air Traffic Controller Conflict Resolution Strategies.* ASA.01.CORA.2.DEL04-B.RS. Eurocontrol. http://www.eurocontrol.int/eatm/gallery/content/public/library/strategies.pdf [see also summary paper at http://atm2001.eurocontrol.fr/finalpapers/pap134.pdf]

Kirwan, B. and Flynn, M. (2002b). *Towards a controller-based conflict resolution tool – a literature review*. ASA.01.CORA.2.DEL04-A.LIT. http://www.eurocontrol.int/eatm/gallery/content/public/library/litreview.pdf

Kohler, H. (1997). *Economic Systems and Human Welfare: A Global Survey.* Cincinnati, OH: South-Western.

Kuder, F. (1977). Activity interests and occupational choice. Chicago, Science Research Associates.

Lauche, K. (2002). Work motivation and Satisfaction. Course Notes. http://www.part-time-projects.com/Courses/EG5039/OandP%20distance%20text%201.pdf

Leroux, M. (1997). *Cognitive Aspects and Automation*. http://atm-seminar-97.eurocontrol.fr/leroux.htm

Louisiana Integrated Skills Assessment (2005). http://www.ioscar.org/la/help/oscarhelp.asp

Magill S.A.N. (1997). Trajectory predictability and frequency of conflict-avoiding action. In, *CEAS 10th European Aerospace Conference on Free Flight,* Amsterdam, paper 34-1.

Mullins, L. (2002). Management and Organisational Behaviour (6th edition) Prentice Hall.

Nijhuis, H. (2000) *Role of the Human in the Evolution of ATM (RHEA). Final Report.* NLR: Netherlands. http://europa.eu.int/comm/transport/extra/web/downloadfunction.cfm?docname=200310/rhearep.pdfandapptype=application/pdf

Pavet, D. (2000). Lessons learnt from CENA-PHARE experiment and requirements for future evaluation of novel concepts in ATC. *Proceedings of 3rd USA/Europe Air Traffic Management RandD Seminar,* Napoli. http://atm-seminar-2000.eurocontrol.fr/acceptedpapers/pdf/paper89.pdf

Pichancourt, I. and McGregor, R. (2001). *EVP-CORA1 Real-Time Simulation.* EEC Report No 367. http://www.eurocontrol.int/eec/publications/eecreports/2001/367.pdf

Printemps, A. (2001). *Air traffic management automation in France*. CENA/NT01-138 AIAA 2001 5222 - 1 - American Institute of Aeronautics and Astronautics. http://www.ath.cena.fr/pages/4publ/air_traffic_automation.pdf

Sheridan, T. B. (2000). Function allocation: algorithm, alchemy or apostasy? *International Journal of Human-Computer Studies. 52,* 203-216.

Swierstra, S. and Green, S. M. (2003). Common Trajectory Prediction Capability for Decision Support Tools. In, *Proceedings of 5th USA/Europe Air Traffic Management RandD Seminar,* Budapest. http://atm2003.eurocontrol.fr/?action=show_attach_onlineandpaper_id=59andtitle=Common+Trajectory+Prediction+Capability+for+Decision+Support+Tools

Whitfield, D. (1982). Some human factors aspects of computers in air traffic control. *In, Proceedings of Conference on Human Factors in Computing Systems* (pp. 268 – 274). Gaithersburg, Maryland. http://delivery.acm.org/10.1145/810000/801792/p268-whitfield.pdf?key1=801792andkey2=6725126011andcoll=GUIDEanddl=GUIDEandCFID=36858020andCFTOKEN=30094775

Whysall, P. (1998). Future Area Control Tools Support (FACTS). *Proceedings of 2nd USA/Europe Air Traffic Management RandD Seminar, Orlando*. http://atm-seminar-98.eurocontrol.fr/finalpapers/track1/whysall.pdf

Wickens, C.D. and Hollands, J. (2000). *Engineering Psychology and Human Performance (3rd Edn.).* Addison Wesley, Longman, New York.

Wilson, I.A.B. (2000). ATM support tools in PHARE – the importance of matching the concepts of management or control. *Proceedings of 3rd USA Europe Air Traffic Management RandD Seminar, Napoli*. http://atm-seminar-2000.eurocontrol.fr/acceptedpapers/pdf/paper55.pdf

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