Rationale behind Performance Shaping Factors for generic human operator models

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Approach
The general approach in determining relevant Performance Shaping Factors (PSFs) was to follow 'Good practices for implementing human reliability analysis' as prepared by the U.S. Nuclear Regulatory Commission and published as NUREG 1792 [NUREG 2005]. In particular, Appendix B of that report provides 'guidance on consideration of performance shaping factors'. Although that appendix was written 'for the specific purpose of addressing post-initiator HFEs in a risk assessment for commercial nuclear power plant operations occurring nominally at full power, and for internal initiating events', much of it is considered useful to other modes of operations and for other industry applications.

It is acknowledged in the guidance document that the way in which PSFs are defined may differ somewhat across HRA methods and tools. The guidance document describes 15 Performance Shaping Factors.

1. Applicability and suitability of training / experience
2. Suitability of relevant procedures and administrative goals
3. Availability and clarity of instrumentation
4. Time available and time required to complete the act, including the impact of concurrent and competing activities
5. Complexity of the required diagnosis and response, the need for special sequencing, and the familiarity of the situation
6. Workload, time pressure and stress
7. Team/crew dynamics and crew characteristics
8. Available staffing / resources
9. Ergonomic quality of the human – system interface
10. Environment in which the action needs to be performed
11. Accessibility and operability of the equipment to be manipulated
12. Need for special tools
13. Communications and whether one can be easily heard
14. Special fitness needs
15. Consideration of 'realistic' accident sequence diversions and deviations.

For the purpose of the human performance models of CATS, the 15 PSFs of NUREG 1792 were used as the starting point. For each of the human performance models it was decided which of these PSFs were relevant and which were not, using the guidance on consideration of PSFs in appendix B of NUREG 1792. Next, for the relevant PSFs it was determined how the 'value' of that PSF could best be described. While doing so, we assumed that the human operators which are the subject of the models have Western Europeans habits and comply with existing regulations.

Flight crew
Applicability of PSFs
This section describes, for each of the 15 performance shaping factors, the considerations for determining their applicability to the flight crew.

<u>Applicability and suitability of training / experience</u>
This is considered to be an relevant factor. Although flight crew can be considered 'trained at a minimum level' to perform their tasks, the degree of familiarity with the tasks to be performed influences the likelihood of success. This degree of familiarity depends on the training and the experience.

<u>Suitability of relevant procedures and administrative goals</u>
This is an relevant factor. For the most part, procedures exist to cover many types of sequences and flight crew actions in normal and abnormal situations.

Availability and clarity of instrumentation
On a flight deck, the instrumentation is an integral part of the human system interface. Therefore this PSF is combined with PSF 'ergonomic quality of the human-system interface' and further discussed under that heading.

Time available and time required to complete the act.
This factor is considered relevant if there is not enough or barely enough time to act. It is clearly related to PSF 'workload, time pressure and stress'. Therefore this PSF is combined with PSF 'workload, time pressure and stress' and further discussed under that heading.

Complexity of the required diagnosis and response, the need for special sequencing, and the familiarity of the situation
This factor attempts to measure the overall complexity of the situation at hand and of the action itself. It includes such measures as the number of steps to be performed in rapid succession, the degree of mental effort involved, whether it is a multi-variable or single variable associated task, etc. It is considered relevant.

Workload, time pressure and stress
This is about the amount of work a flight crew has to accomplish in the time available, along with their overall sense of being pressured or threatened in some way with what they are trying to accomplish. If the scenario is familiar, the procedures and training for the scenario are good, and the rate at which the crews normally implement their procedures will allow them to achieve their goal on time, even relatively high expected levels of workload and stress will not have a significant effect on performance [NUREG 2005]. Therefore, workload is particularly considered relevant for abnormal situations.

Team/crew dynamics and crew characteristics
This PSF addresses the degree of independence among crew members and their approach for implementing procedures (e.g. aggressive vs. methodical). Because a flight crew consists of two persons this factor is considered relevant.

Available staff / resources
For flight crew this is not a relevant consideration. The number of flight crew members is fixed and without a complete crew the aircraft cannot depart.

Ergonomic quality of the human system interface.
In the case of flight crew, the human system interface is the flight deck and is considered relevant. This PSF will be integrated with 'Availability and clarity of instrumentation'.

Environment in which the action needs to be performed
The internal environment is not particularly relevant for flight crew actions given the habitability control of flight decks and the rare challenges to that habitability. The external environment cannot be controlled however and is considered relevant. For flight crew, the external environment is the weather.

Accessibility and operability of the equipment to be manipulated
As with the internal environment factor, this factor is not particularly relevant to cockpit operations. All controls are designed to be operator from the pilot's seat.

Need for special tools
As for the internal environment and accessibility factors, this factor is not particularly relevant to cockpit operations.

Communications and whether one can be easily heard.
This is about the possibility that directives are misunderstood. For flight crews it concerns communication within the cockpit (between captain and first officer) and communication with air traffic control. Both are considered relevant.

Special fitness needs
Physical fitness is not considered an issue for flight crews because of the regular medical checks and regulations regarding retirement, but fatigue should be considered. Crew fatigue is quite often mentioned as a factor in accidents and is considered relevant.

Consideration of 'realistic' accident sequence diversions and deviations
This PSF describes the extent to which the actual sequence of events appears to be similar to how it is trained in the simulator. Although a large part of flight crew training takes place in flight simulators this PSF is not considered a relevant issue because of the level of fidelity of current flight simulators.

In conclusion, the following PSFs are considered relevant for the flight crew:
- Applicability and suitability of training / experience
- Suitability of procedures
- Complexity of the required diagnosis and response
- Workload, time pressure and stress
- Team/crew dynamics and crew characteristics
- Ergonomic quality of the human – system interface
- External environment
- Communications and whether one can be easily heard
- Special fitness needs

Expressing PSFs in units
The next step in the process is to establish for the relevant performance shaping factors, the possibilities to express their values in objectively quantifiable units.

Training and experience
The degree of familiarity with the task to be performed influences the likelihood of success. This degree of familiarity depends on the training and the experience.

Flight crew receive three types of training: technical knowledge, technical skills and non-technical skills. Technical knowledge is trained at ground school and technical skills are covered in the initial and recurrent type training. Training of non-technical skills is primarily covered in the Crew Resource Management (CRM) training. Both the content and the frequency of training are considered to be relevant factors. Factors that have a positive influence are:
- Training is current
- Training is like the real event
- Training represents differences in the way an event van evolve
- Proficiency is demonstrated on a periodic basis.

Periodic demonstration of proficiency is covered in regulatory requirements for flight crew and is not considered relevant here as there will hardly be differences among flight crew. The content of the training is covered by the second and third bullet. It is considered relevant but at this stage impossible to quantify in objective units. The first bullet (currency of training) is kept as PSF because it can be quantified. The number of days since the last type recurrent training will be used in the model to quantify currency of training, and this will thus will be used as a proxy for 'training'.

Experience expresses the number of times the pilot has encountered a given situation before. It can be obtained in operational practice or in training. As a simplification, experience of a pilot can be expressed as total number of hours, number of hours on type, and total number of aircraft types flown. Total number of hours and hours on type are considered to be equally important and are obviously correlated. Total number of types flown is considered to be less relevant. Because information on total number of hours is more easily obtained than hours on type and more relevant than total number of types flown, total number of hours is selected as the appropriate unit to represent pilot experience. A distinction is made between the Captain and the First Officer.

Suitability of procedures
Characteristics that have a negative influence on the suitability of procedures are:
- Ambiguity
- Need to rely on memory
- Situations in which flight crew must perform calculations
- Situations for which there is no procedure

The difficulty here is that these characteristics can vary from procedure to procedure, and there are many different procedures to consider. For each aircraft type the aircraft manufacturer will write procedures for normal and abnormal tasks. The airline will base its own procedures on those of the manufacturer, but can deviate, for instance to be in accordance with the standard operating procedures that apply to the airline irrespective of the aircraft type. In addition to that, there are the airport's arrival and departure procedures that are different for each runway at each airport.

Because of these many procedures, it is practically impossible to assess each procedure on characteristics like ambiguity, need to rely on memory, etc. We could try to look at groupings of procedures and consider general differences between for instance Boeing and Airbus procedures, or between KLM and BA procedures, but this is not considered feasible. Therefore this PSF is not taken into account.

Complexity of the required diagnosis and response

Factors that influence the complexity of the situation at hand are traffic density, complexity of the route structure (SIDs and STARs), possible flight delays, amount of information available, and the technical status of the aircraft. Although each of the mentioned aspects does play a role, it is difficult to clearly define and quantify the combination of these aspects. Arguable the most relevant factor is the complexity of the route structure during departure and arrival, but as of yet we have not been able to represent this in objectively quantifiable units. At this stage it is considered to be too complex to represent the air traffic complexity and density in the flight crew performance model, but it is recommended to continue exploring possible ways to represent this aspect in future versions of the model.

Workload, time pressure and stress

In the context of flight crew activities, workload can be defined as all the physical and mental effort required to fly an aircraft. It includes planning, thinking, navigation, communication, and controlling the aircraft [Stein & Rosenberg 1983]. High workload exists when task demand is close to the operator's maximum capacity, while workload is low when task demand is much below the operator's capacity. Hence, workload is not only sensitive to multiple characteristics of a task, i.e. task demand, but also of the operator, i.e. operator capacity [Hart 1987, Hancock et al. 1995]. Operator capacity is highly influenced by fatigue, training and experience of the flight crew. This is already represented in other PSFs. To avoid double counting we will therefore only consider aspects of task demand. Task demand is determined by the type of action, the number of actions, the sequence of the actions and the time required for the action to be completed [Lysaght et al. 1989]. If the scenario is familiar, the procedures and training for the scenario are good, and the rate at which the crews normally implement their procedures will allow them to achieve their goal on time, even relatively high expected levels of workload and stress will not have a significant effect on performance. Therefore, workload is particularly considered relevant for abnormal situations.

For a flight crew, a situation can be abnormal because of the environment outside (traffic and weather) or because of the technical status of the aircraft. An abnormal situation because of the technical status of the aircraft is easily defined as whether or not there is a situation that requires the flight crew to consult the abnormal procedures section of the Aircraft Operations Manual (AOM). Therefore this was selected as the proxy variable for 'workload, time pressure and stress'.

Team/crew dynamics and crew characteristics

The composition of the flight crew is expected to influence flight crew coordination and cooperation and hence affect the flight crew error probability. The ability of captain and first officer to work together as a team depends on cultural and psychosocial factors and can also be influenced by experience, training, and airline procedures. Trans-cockpit authority gradient is a potentially relevant factor. A steep trans-cockpit authority gradient may exist when the captain has much more experience than the first officer, but it is also influenced by national culture. At this stage it is considered to be too complex to represent trans-cockpit authority in the flight crew performance model, but it is recommended to continue exploring possible ways to represent this aspect in future versions of the model.

Ergonomic quality of the human – system interface

The quality of the interface between machine (the aircraft) and its human operator (the flight crew) has greatly improved over the years. This can be illustrated by comparing the cockpit of a first generation commercial jet transport aircraft like the De Havilland DH-106 Comet, with that of a modern jet airliner like the Boeing 777. When considering the effect of technological advances on safety of air transport it is common to consider four different generations of aircraft since the introduction of the jet engine. First generation aircraft are typically designed in the 1950s. Most of the aircraft were certified before 1965 according to British Civil Airworthiness Requirements (BCAR's) or other certification bases. Jet engines were still very new, and the aircraft had very limited cockpit automation, simple navigational aids and limited approach equipment. Examples are the DH Comet, Fokker F-27 and Boeing 707. Second generation aircraft, designed in the 1960s and 1970s, have more reliable engines. The aircraft were certified between 1965 and 1980, not yet based on common JAR-25/FAR-25 rules. Cockpit equipment is more advanced, with better auto pilots, auto throttles, flight directors and better navigational aids. Examples of second generation aircraft are Fokker F-28, Boeing 737-200 and Airbus A-300. Third generation aircraft, designed in the 1980s and 1990s, typically show considerations for human factor aspects in the cockpit. Electronic Flight Instrument Systems (EFIS) and improved auto pilots are being used. Furthermore, the aircraft are equipped with ACMS data systems and high-by-pass engines designed according to higher certification standards. Examples of third generation aircraft are Fokker 50 and Boeing 737-700. Fourth generation aircraft like the Airbus A 320 and Boeing 777 have fully glass cockpits and digital fly-by-wire systems. Those different aircraft generations provide a convenient classification for the quality of the man-machine interface. Research has shown that the probability of flight crew error is significantly reducing for subsequent aircraft generations. [Roelen and Wever 2002].

External environment

Weather influences aircraft safety in a complex way. Some weather phenomena are a direct hazard in itself, for instance lightning, microbursts or conditions that result in airframe icing. Other conditions may influence the degree of difficulty of the flying task, such as gusting winds or reduced visibility due to heavy rain or fog. Weather may also create a less comfortable working environment, for example prolonged flight in turbulence is physically rather demanding. Arbitrarily, the rainfall rate has been selected as the indicator of weather in this model. The rainfall rate is observable by pilots, it determines the colour painted by the weather radar in the cockpit, it influences visibility and heavy rainfall also can increase the noise level in the cockpit. The rainfall rate therefore corresponds to some extent with the pilot's perception of 'bad weather'. Heavy rainfall is also correlated with stormy, turbulent weather and thunderstorm activities, and is therefore able to capture many of the weather related hazards.

Communications and whether one can be easily heard

Without communication the flight crew cannot work together as a team. Because flight crews as positioned side by side on the flight deck, and because the ambient noise levels are the flightdeck are not excessive, the issue is not so much whether one can easily be heard, but more whether one can easily be understood. Phraseology is generally not considered to be a problem because the Standard Operating Procedures also cover phraseology, but communication is assumed to be affected by the native language of the captain and the first officer. For the purpose of this model, flight crew composition and communication is represented by the factor 'delta mother tongue' which represents whether the captain and first officer speak a different native language.

Communication is not only relevant within the cockpit but also from the cockpit to ATC. The aspect of communication between flight crew and ATC represents a special case as it links the flight crew performance model and the air traffic controller performance model. A first attempt to represent this factor is described in [Singuran 2008].

Special fitness needs

A person's physical condition has significant influence on performance. The physical conditional is affected by a myriad of factors such as eating habits, age, diseases, the use of medication, and the time of day. Generally speaking people perform less well during the early hours in the morning [Rosekind et al 1994]. Representing that influence in a model for flight crew performance is complicated by the fact that pilots regularly cross time zones. Up to 10 time zone crossings in a single flight are no exception. It is therefore rather arbitrary what should be considered 'time of day' for a pilot: local time at the location of the aircraft or local time at the point of departure? And what should be considered the 'time of day' for a pilot who flies from Amsterdam to Los Angeles (crossing 9 time zones), has a stopover of one night, and then flies back to Amsterdam? Another point of consideration is the correlation between time of day and fatigue. Flight crew fatigue has also been the subject of extensive research [Simon & Valk 1993, Simons et al 1994, Simons & Valk 1997, Simons & Valk 1998, Valk & Simons 1996] and data on fatigue levels is available from that research. Because fatigue is less complicated to represent, because of the availability of data, and because time of day and fatigue are correlated, it is proposed to represent only fatigue in the model, and not to represent time of day or any other factor that could influence a pilot's physical condition.

Fatigue will be quantified using the Stanford Sleepiness Scale (SSS). The result of the SSS is a score with increasing sleepiness from 1 to 7, where 1 signifies "feeling active and vital; wide awake" and 7 stands for "almost in reverie; sleep onset soon; losing struggle to remain awake". The 7 points scale is listed in Table 1. SSS measures are highly correlated with flying performance and threshold of information processing speed during periods of intense fatigue [Roelen et al 2002].

Table 1: Stanford Sleepiness Scale

Degree of Sleepiness	Scale Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7

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Air Traffic Controller
Applicability of PSFs

This section describes, for each of the 15 performance shaping factors, the considerations for determining their applicability to the air traffic controller.

<u>Applicability and suitability of training / experience</u>
This is considered to be an relevant factor. Although air traffic controllers can be considered ‘trained at a minimum level’ to perform their tasks, the degree of familiarity with the tasks to be performed influences the likelihood of success. This degree of familiarity depends on the training and the experience.

<u>Suitability of relevant procedures and administrative goals</u>
For the most part, procedures exist to cover many types of sequences and air traffic controller actions in normal and abnormal situations. Because of the high degree to which the procedures clearly and unambiguously address the actions to be performed by air traffic controllers, this factor is not considered to be relevant.

<u>Availability and clarity of instrumentation</u>
For an air traffic controller, the instrumentation is an integral part of the human system interface. Therefore this PSF is combined with PSF ‘ergonomic quality of the human-system interface’ and further discussed under that heading.

<u>Time available and time required to complete the act.</u>
This factor is considered relevant if there is not enough or barely enough time to act. It is clearly related to PSF ‘workload, time pressure and stress’. Therefore this PSF is combined with PSF ‘workload, time pressure and stress’ and further discussed under that heading.

<u>Complexity of the required diagnosis and response, the need for special sequencing, and the familiarity of the situation</u>
This factor attempts to measure the overall complexity of the situation at hand and of the action itself. It includes such measures as the number of steps to be performed in rapid succession, the degree of mental effort involved, whether it is a multi-variable or single variable associated task, etc. It is considered relevant.

<u>Workload, time pressure and stress</u>
This is about the amount of work an air traffic controller has to accomplish in the time available, along with their overall sense of being pressured or threatened in some way with what they are trying to accomplish. It is considered relevant and is combined here with the PSF time available and time required to act.

<u>Team/crew dynamics and crew characteristics</u>
This PSF addresses the degree of independence among air traffic controllers and their approach for implementing procedures (e.g. aggressive vs. methodical). For air traffic controllers this is not considered relevant because their tasks are such that they can work rather independently and much less as a team compared to for instance a flight crew.

<u>Available staff / resources</u>
For air traffic controllers this is not a relevant consideration since the air traffic control organisation will assign appropriate qualified staff to stand-by duties. These stand-by staff can be made available whenever there is a shortage of personnel due to e.g. sickness.

<u>Ergonomic quality of the human system interface.</u>
The human system interface is considered relevant for air traffic controllers. This PSF will be integrated with ‘Availability and clarity of instrumentation’.

<u>Environment in which the action needs to be performed</u>
The internal environment is not particularly relevant for air traffic controllers given the habitability control of control rooms and the rare challenges to that habitability. Temperature and lighting can be adjusted, noise levels are not problematic and vibration is not an issue. Of the external environment,

visibility is a relevant factor for air traffic controller situated in the control tower as this will directly influence the way in which they perform their tasks. For area controllers however the visibility is not relevant.

<u>Accessibility and operability of the equipment to be manipulated</u>
As with the environment factor, this factor is not particularly relevant to air traffic controller operations. All equipment is easily accessible. Issues such as layout of computers, angle of vision etc. fall under 'ergonomic quality of the human-system interface'.

<u>Need for special tools</u>
As for the environment and accessibility factors, this factor is not particularly relevant to air traffic controllers.

<u>Communications and whether one can be easily heard.</u>
This is about the possibility that directives are misunderstood. For air traffic control it concerns communication with other air traffic controllers and communication with flight crews. Both are considered relevant.

<u>Special fitness needs</u>
Physical fitness is not considered an issue for air traffic controllers. Fatigue is also not considered to be relevant due to the relative short shift duration (typically 2 hours maximum) and applicable duty time regulations.

<u>Consideration of 'realistic' accident sequence diversions and deviations</u>
This is considered relevant in case of potential diversions and distractions that may delay response timing or confuse the operators as to the appropriate actions to take. This is not considered relevant for air traffic controllers.

In conclusion, the following PSFs are considered relevant for the air traffic controller:

- Applicability and suitability of training / experience
- Complexity of the required diagnosis and response
- Workload, time pressure and stress
- Ergonomic quality of the human – system interface
- External environment
- Communications and whether one can be easily heard

Expressing PSFs in units

The next step in the process is to establish for the relevant performance shaping factors, the possibilities to express their values in objectively quantifiable units.

<u>Applicability and suitability of training / experience</u>
Experience of an air traffic controller can be expressed as the overall experience as an air traffic controller and as experience on a particular position, like e.g. area controller, runway controller, etc.. In this study we refer to experience as the number of years working as an air traffic controller in the current position because this is considered to be the most relevant.

Suitability of training is about whether the training is like the real event. Because training of air traffic controllers is for a large part conducted 'on the job' this factor is not particularly relevant.

<u>Complexity of the required diagnosis and response</u>
Factors that influence the complexity of the situation at hand are traffic density, complexity of the route structure, traffic diversity (causing e.g. speed differences and different minimum separation distances), etc. Although each of the mentioned aspects does play a role, it is difficult to clearly define and quantify the combination of these aspects. Arguable the most relevant factor is the complexity of the route structure, but as of yet we have not been able to represent this in objectively quantifiable units. At this stage it is considered to be too complex to represent the air traffic complexity in the air traffic controller model but it is recommended to continue exploring possible ways to represent this aspect in future versions of the model.

<u>Workload, time pressure and stress</u>

The common traditional index of workload measurement in air traffic control is the number of aircraft under supervision [Collet et al 2003, Averty et al 2004]. Other factors such as traffic diversity and the complexity of air routes are known to influence controller workload as well, but as of yet we have not been able to represent these characteristics in objectively quantifiable units. Workload for the controller is therefore expressed in this model as the number of aircraft simultaneously under control of a single controller.

Ergonomic quality of the human – system interface

Air traffic controllers are supported by various technological systems to perform their tasks safely and efficiently. The most basic tool is VHF radio, which is used for voice communication with the flight crew on-board the aircraft. In addition to radio, most air traffic controllers use radar. A controller's radar screen depicts the various aircraft flying within his area of responsibility. Primary radar sends out an energy pulse of which a small part is reflected by objects such as aircraft. A controller sees these objects as 'blips' on his radar screen. Secondary radar interrogates a transponder on-board the aircraft, upon which the transponder sends back relevant information. Each aircraft on the controller's radar screen is then indicated by a label that contains specific information like the flight number and the current altitude of the aircraft.

The availability of radar depends on practical and financial feasibility. The Atlantic and Pacific routes for instance are not covered by radar due to the limited range of the land based radar antennas. Time based separation is used on those routes and the flight crews must report their position via radio. Some parts of Africa are also not covered by radar. The area controllers there have to rely on time based separation with VHF radio as their only equipment.

On modern high capacity airports, the air traffic controllers often have additional equipment available to help them perform their tasks safely and efficiently. Examples of such equipment are:

- Ground radar, possibly with ground labels
- Runway Incursion Alerting System (RIAS)
- Converging Runway Display Aid (CRDA)
- Short Term Conflict Alert (STCA)
- Minimum Safe Altitude Warning (MSAW)
- Final Approach Spacing Tool (FAST)

From this overview it is evident that large differences may exists between air traffic controllers with respect to the available equipment. Given the many air traffic control equipment design reviews and improvements and the daily familiarity of the work stations, problematic human-system interfaces are supposed to have been taken care of. It is therefore considered not relevant to try to rate the ergonomic quality of each possible type of equipment. Instead, it was decided to consider the type of equipment in general that is available to the controller. The following four classes are distinguished for this purpose (keeping in min that the model should be able to represent the global aviation system):

1. VHF radio only,
2. VHF radio and primary radar,
3. VHF radio, primary radar and secondary radar,
4. VHF radio, primary radar, secondary radar and additional tools like RIASS, STCA, etc.

External environment

Activities of air traffic controllers in the control tower are directly influenced by the visibility conditions. When visibility is reduced the controllers are less able to observe directly what is happening on the airfield and the working procedures will change when visibility drops below certain pre-set threshold values. At Schiphol the following visibility conditions are distinguished:

- Normal operations: Runway Visual range (RVR) more than 1500 m and cloud base above 300 ft.
- BZO A: RVR between 550 m and 1500 m or cloud base between 200 ft and 300 ft (associated with Cat 1 approaches).
- BZO B: RVR between 350 m and 550 m or cloud base below 200 ft (associated with Cat II approaches).
- BZO C: RVR between 200 m and 350 m (associated with Cat 3a approaches).
- BZO D: RVR below 200 m (associated with Cat 3b approaches).

These visibility classes determine the procedures used by the tower controllers. The minimum separation distance on final approach for instance increases with lower visibility and for low visibility ranges the ILS sensitive areas at the airport must be clear of all traffic (this is to avoid disturbance of the ILS signal due to e.g. reflections). In general low visibility ranges will limit the movement rates of the airport.

Because of the existence of distinct visibility classes that have direct consequences for the procedures to be followed, it was decided to use the visibility class (instead of the visibility itself) as the unit of measure of the external environment.

<u>Communications and whether one can be easily heard</u>
Air traffic controllers need to coordinate their activities with those of other controllers in their own organisation as well as controllers in other organisations, e.g. when an aircraft is handed over from one sector to another. Much of the communication between air traffic controllers is done with the use of ‘flight strips’. Each strip contains information on a particular aircraft and is passed over from one controller to another. The strips used to be of paper but many control organisations are transferring to electronic flight strips. Electronic flight strips have as advantage over paper strips their ability to interface with other electronic equipment, but a paper strip allows more flexibility in its use and they are portable, which is important for the way in which the controllers interact with them [Mackay 1999, Pavet 2001]. Whether paper strips or electronic strips are used might be a relevant parameter to consider, but at this stage we do not have sufficient data (experiment, expert judgement or operational experience) to substantiate this.

Voice communication among air traffic controllers is also relevant. When two controllers are located in the same room (e.g. the control tower) this voice communication will usually be done without additional equipment, but when two controllers are located in different rooms or even in different rooms, some type of equipment such as telephone, radio, fax or a combination will have to be used for voice communication. Because of the low ambient noise levels in control rooms, voice communication among air traffic controllers located in the same room is not considered a problem. When some type of equipment is used (radio, telephone, etc) to communicate there is a possibility of disturbance of the signal. Ideally, variables like the signal to noise ratio of this communication are used to express this value, but this is not very practical as no data are available. The best we could do is to assume a value for the signal to noise ration of each type of equipment used, but then we can just as well simply indicate which equipment is used without bothering about the true signal to noise ratio. A further simplification is obtained by limiting this parameter to a Boolean variable which indicates whether or not the controllers are located in the same room, i.e. whether or not equipment is used for communication. Therefore communication among air traffic controllers is represented in the model by this Boolean variable.

The aspect of communication between flight crew and ATC represents a special case as it links the flight crew performance model and the air traffic controller performance model. A first attempt to represent this factor is described in [Singuran 2008].

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