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Vision on the implementation of new technology in the control tower

Customer

Knowledge Development Centre Mainport Schiphol

NLR-TR-2013-419-RevEd-1 - May 2014

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May 2014

Customer	Knowledge Development Centre Mainport Schiphol
Contract number	KDC2013014
Owner	Knowledge Development Centre Mainport Schiphol
Division NLR	Air Transport
Distribution	Limited
Classification of title	Company Confidential
Date	May 2014

Approved by:

Author	Reviewer	Managing department
G.D.R. Zon	H. van Dijk	H.G.M. Bohnen
Date	Date	Date

Summary

New technologies continuously emerge in the air traffic control tower. These are generally implemented to solve problems that exist in the tower at that moment, or to replace systems that are end of life or no longer up to standard.

A more proactive approach would support staying ahead and use the available technology where it can help out. With respect to future developments it would be helpful to have a generic vision which can be used to make adequate decisions on how to design the work environment and to verify whether each new development matches with the higher level plan for the tower and for the airport environment.

A vision on the future work environment includes envisioning the role of the human, the role of the system, and the integration of the human and the system in the tower.

The aim of this vision is to support LVNL when introducing new technologies into the tower at Schiphol. In the continuously changing world this vision can serve as kind of beacon to evaluate for each individual development whether it matches or not with the higher level goals or strategies.

This study provides that generic vision. It should be seen as a study in addition to specific visions that already exist at LVNL regarding:

- Operations
- Tower technologies
- Human factors

It does not replace these visions; it supports their integration.

This document provides such a vision for the control tower at Schiphol airport; it covers a period of approximately twenty years.

Description of work

In order to create a vision on the implementation of new technology in the control tower, different techniques were combined. After initial discussions with LVNL staff, information exchange regarding the visions that LVLNL already has and a literature survey, an initial vision was formulated, thereupon several iterative steps were taken to fine-tune that vision.
These steps comprised:

- A literature study on research that looks into the future of ATM (Flightplan 2050, SESAR, EARA, etc.), experiences in other domains (cockpit), scientific articles on automation, new developments in ATM, relevant projects that NLR was involved in in the past.
- A visit to the tower at Schiphol airport and interviews with operational experts.
- A workshop with operational experts, human factors specialists, systems engineers, and researchers to discuss the first draft vision and adjust and enrich it.

Results and conclusions

The vision itself is built upon nine main trends that were foreseen to develop further in the coming years. The trends are based upon building blocks that cover both technological changes or opportunities from within and outside the world of air traffic control, and human factors aspects indicating the role of the human in a complex system. The nine trends that form the base for this vision are:

- Information presented according to the operational role
- Customisable and uniform working position
- Information integration
- Consistent Human Machine Interface
- Support for human sensors
- Automation philosophy
- Intelligent Agents
- Shift from tactical to more planned operation
- Increased teamwork and more flexible teams

The vision is accompanied by a set of so called Golden Rules. These rules form a list, based upon the trends, to take into account when introducing changes in the tower. The rules will support to make any change, as much as possible, match with the general vision.

Applicability

LVNL can use this vision to make proper decision on advancements in the tower in the future.

The vision creates a common ground for human factors, machine and procedures and therefore ensures that different but interdependent disciplines work towards one goal based upon one single vision.

The vision itself is intended for a wider audience, including human factors specialists, system and procedural designers, and air traffic controllers.

Content

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Abbreviations

Acronym	Description
AAS	Amsterdam Airport Schiphol
ADAHR	Assessment of Degree of Automation on Human Roles
ADS-B	Automatic Dependent Surveillance-broadcast
ANSP	Air Navigation Service Provider
AR	Augmented Reality
ART	Advanced Remote Tower
A-SMGCS	Advanced-Surface Movement, Guidance, and Control System
ASS	Assistants
ATC	Air traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
BYOD	Bring Your Own Device
COTS	Commercial Off The Shelf
CPDLC	Controller-Pilot Data Link Communication
C-SHARE	Joint ATM Cognition through Shared Representations
CTR	Control Zone
Digi Strip	Digital Flight Strip, or Electronic Flight Strip
EDD	Electronic Data Display
EFB	Electronic Flight Back
GC	Ground Controller
HF	Human Factors
IA	Intelligent Agent
ICAO	International Civil Aviation Organization
ITWP	Integrated Tower Working Position
KDC	Knowledge Development Centre Mainport
LoA	Levels of Automation
LVNL	Lucht Verkeersleiding NederLand
MABA-MABA	Men Are Better At / Machines Are Better At
NLR	National Aerospace Laboratory
NRC	National Research Council
OODA	Observe, Orient, Decide, and Act
R&D	Research and Development
RC	Runway Controller
RPAS	Remotely Piloted Aircraft System
RWY	Runway
SA	Situational Awareness
SUP	Supervisor

TWR-C	Tower Centre
TWR-W	Tower West (to monitor Polderbaan RWY 18R – 36L)
WL	(mental) Workload

1 Introduction

1.1 The need for a vision

In recent years several technologies have become available that digitise operational information and can support the operational processes in the control tower at Schiphol airport. These technologies are often relatively easily implementable tools that support air traffic controllers (ATCOs) in their tasks as well as ensure safety net functions. While these technologies seen in isolation may have beneficial effects on human performance, the combination of technologies, especially when not truly integrated, may have a negative impact on controller working processes, and ultimately on safety.

This study provides a generic vision for the integration of technologies and human factors in the tower. It should be seen as a study in addition to specific visions that already exist regarding operations (Noordam, 2013), tower technologies (Noordam-Bolding and Berar, 2013) or human factors (Huisman and Schuver-van Blanken, 2013). It does not replace these visions; it supports their integration.

The Knowledge Development Centre (KDC) asked the National Aerospace Laboratory (NLR) to formulate a vision for implementation of new technologies in the control tower to provide a clear and human-centred direction for the development of tower technologies in the future (KDC Purchase order: KDC2013014). The trends reflected in this vision are generic and are, to a certain extent, also applicable in a broader context than the Schiphol control tower.

1.2 Formulating a vision

Before a vision for implementation of new technologies in the control tower of Schiphol airport is formulated, it is helpful to take a step back and clarify two key terms relevant in this document: vision and control tower.

1. The *vision* describes a trend-based impression of the future situation and what has been achieved by then. It is not just based on facts and scientific research, but incorporates opinions and even dreams. A vision provides guidance about how things are expected to behave and form the base for strategic decisions. A vision is a starting point for goal-directed developments. These developments may comprise issues that are no problem now, but might become problems in the future. Applying a vision is about anticipating upon issues before they actually turn into problems and about designing an environment that fits in a foreseen future situation.

2. The *control tower* is the central place in which aerodrome control is carried out. Aerodrome controllers are responsible for the separation and efficient movement of aircraft and vehicles operating on the taxiways and runways of the airport, as well as of aircraft in the air in the immediate vicinity of the airport. The area of responsibility of aerodrome controllers is the so-called Control Zone (CTR) and at LVNL the unit involved is referred to as Tower (TWR). Within TWR, there are three functional roles, corresponding to three areas of responsibility:

- Clearance Delivery/Start-up Controller (DEL/SUC);
- Ground Controller (GC); and
- Runway Controller (RC), also known as Tower Controller.

This team of controllers is typically supported by one or two Assistants (ASS) and guided by a TWR Supervisor (SUP)

Throughout the document the term “operational staff” is used to indicate all roles that work in the tower. This includes ATCOs (ground and tower), assistants, supervisor, etc. The specific roles of operational staff will only be used when something is described that solely comprises one role.

The vision takes the foreseen developments in and around the tower as starting point and, based upon expected operational trends for the future, describes the foreseen (technological) developments that the human operational staff member will be confronted with.

An exact prediction of the developments over the coming 20 years is hard to give. The vision can serve as a source of inspiration and a guideline to make adequate decisions on how to design the work environment and to verify whether each new development matches with the higher level plan for the tower and for the airport environment.

1.3 Approach

The vision will be based upon pre-existing knowledge within NLR and NLR’s R&D network. It will also be based upon literature surveys and discussions with operational staff during a visit to the Schiphol tower, several meetings with LVNL staff, including operational ground- and approach controllers and a workshop (see Appendix A) that will be organised for the LVNL staff.

The LVNL staff that will be actively involved in those meetings, and also in the review process of this document comprises: M.I. Roerdink, H. Huisman, M.J. Schuver – van Blanken, S. Noordam and I.L. Berar.

After initial discussions with LVNL staff, information will be gathered, sorted and an initial vision will be formulated. After this, literature surveys and the other discussions with operational staff will be applied in an iterative manner to fine-tune and complete the vision.

The Delft University of Technology was asked to provide a review of the concept document “Vision on the implementation of new technology in the control tower”, as sent on January 26, 2014. As requested, the review focused on checking the completeness of the vision. This review was completed by M.M. (René) van Paassen, associate professor.

LVNL will also provide documentation about the tower (layout and systems) the procedures and the existing operational, tower system and human factors visions. These will also be used as background knowledge to get the research team quickly into the loop, though given the target audience (LVNL staff) of this document the LVNL input will not be explicitly summarised in the literature survey that was executed for this work.

1.4 This document

In Chapter 2 the final result of this study: “A vision on implementation of new technology at Schiphol control tower” is described. The vision itself is intended for a wider audience, including human factors specialists, system and procedural designers, and air traffic controllers. The document provides in Chapter 3 a description of nine main trends that were observed, which led to the vision. Besides a description of the trends themselves also the reasons why these trends will develop and the advantages and disadvantages to take into account when applying the vision are listed there. The elements that led to the vision, as well as an overview of potentially relevant developments related to human machine interaction are gathered in Chapter 4. At the end of Chapter 3 a reading guide is included that links the different trends from Chapter 3 to the building blocks in Chapter 4. Finally the limited set of rules, or guidelines - together called the “Golden Rules” - which are provided in Chapter 5 describe what to take into account when implementing changes in the tower.

2 A vision on implementation of new technology at Schiphol control tower

ATC the Netherlands (LVNL) provides air navigation service at a high service level at a complex airport. The highly competent experts working at Schiphol Tower significantly contribute to a safe and efficient air traffic flow. In order to excel in air navigation service in the future, and to keep up with current and upcoming developments LVNL needs a vision for the implementation of new technology at Schiphol Tower. The aim of this vision is to be ahead of technological, societal and economic developments and anticipate upon, and guide the changes that are needed.

This chapter describes a vision on the implementation of new technology at Schiphol control tower. It is inspired by current and upcoming trends that are expected to potentially influence Schiphol tower in the coming 20 years. The vision described below is based upon current or foreseen trends at the airport, in technology, and air traffic control in general. It has therefore a base, or reason, for existence. The vision is also a mix of technological opportunities and human (factors) aspects related to these changes. It is clear that the human component influences the technology and vice versa.

The purpose of this vision is to enable the formulation of new plans and ideas for the tower and to verify whether these plans and ideas match with general foreseen developments. This facilitates the use of a vision inspired policy with one common goal in mind.

While the vision describes the goals and wishes in the far future, it is important to start preparing for and thinking about these changes now. It is recommended to act ahead of these changes rather than developing solutions that are efficient at the moment but inappropriate later on. This means that the vision is a beacon that can be used during discussions and decision making regarding new technologies, procedures or staffing concepts for Schiphol tower, as well as Schiphol as a whole. The vision is a strategic guideline to determine the relevance and importance of new technology at Schiphol control tower. It is the answer from a joint human-machine cognitive systems perspective to this changing world.

The Vision

In the future the Schiphol control tower is a highly integrated working environment in which men and machine smoothly work together. The operational staff member is responsible for a safe and time-based operation, and supported by automated systems and innovative technology. Tasks with low risk, as well as tactical planning and routine tasks are executed by the system. The operational staff member does what s/he is best in, and the automated system focuses on those tasks where machines excel human operators. The acceptance for high levels of automation is high because most of the operational staff working in the control tower grew up in a digital world with high levels of technology in day to day life and because of the high reliability and quality of automated systems.

The various stakeholders in the Air Traffic management (ATM) network produce large amounts of relevant information, which an advanced airport collaborative decision making (A-CDM) system processes and analyses in the background. The information is subsequently presented according to the need of any operational role in the tower. Role specific information presentation prevents operational staff from cognitive overload and forms an integral part of the design philosophy in the tower. Less can be more, which implies that the content, amount and organisation of information will be customised and adaptable to a specific role. Reliance on warnings and alerts should be minimised as much as possible!

While role specific information is presented to only some individual roles in the tower, information relevant to the entire team is also efficiently integrated in one ”traffic picture” displayed at an air traffic situation display in the tower. The situation display facilitates team members’ shared situational awareness of the traffic situation and helps efficient teamwork, as well as cognitive processing of information. Automated integration of various information sources, such as radar information, meteo data, flow management information, and live feed of aircraft and other vehicles from camera, contributes to a quick perception and interpretation of information. This systematic and meaningful integration of information is therefore a second important element of the design philosophy in the tower. Human perception is also supported by external sensors that, for example, provide live feeds of aircraft and other vehicles from cameras located at the airport or on aircraft. Aerodrome control is no longer limited to the (line of) sight of operational staff but can be extended without losing reliability of the perceived information. Highly advanced sensor-technology ensures that live information is presented without delay and even small changes in the environment, such the turning tail of an aircraft, can be easily perceived. Further the live camera information is enriched with information coming from other sources like, radar, databases, infra-red cameras, etc.

In order to ensure that operational staff can optimally use the integrated and role-specific chunks of information described, a consistent human machine interface prevails in the control tower. This element of the design philosophy includes that the introduction of new tools and interfaces is always evaluated regarding consistency and uniformity of the working position. Consistent human machine interface increases quick and correct use of the system and prevents confusion or inefficiency. In addition, uniformity of working positions makes it possible that any operational staff member can work at any position in the tower. For example, through little adjustment in the personal and function-specific settings a runway controller easily switches to the position of a ground controller and vice versa. Operational roles are no longer tied to one position. All working positions in the tower are where needed equipped with Commercial-Of-The-Shelf (COTS) apparatus, which are either provided by the Air Navigation Service Provider (ANSP) or brought to work by the operational staff. Since a mix of devices can put uniformity at risk, a clear criterion list will exist that defines basic functionalities and properties of the COTS that are allowed for the working positions.

Teams go beyond the physical border of the control tower. This is, a team is not limited to the ATCOs and assistants but include operational staff at the airport, in the cockpit, or at other ANSPs. Furthermore, intelligent agents, in the form of software tools, are part of the team and actively monitor, collect and provide information. They behave goal oriented and their ”intelligence” enable the understanding other team members’ information needs. Whether intelligent agents are part of the team as well as in general the composition and size of a team depends on the operational situation and can be adjusted flexibly. New communication technology allows effective communication disregarding of language and physical distance.

3 Trends

This chapter outlines the background of the vision elements presented in in Chapter 2. The elements were based on trends identified, which will be described in more detail in the following. Each trend is described in terms of the observable change itself. Furthermore, additional information is provided per trend, namely:

1. The influencing forces that drive these trends. This comes down to the reasons why these trends will develop.
2. Comparison with the current situation. This highlights how the described trend will be different from the nowadays situation.
3. The challenges and opportunities that have to be faced when these trends become reality. This summarises what the gain is, and possible side effects, or practical issues to take into account in order to make this trend happen.

The building blocks for these trends stem from Chapter 4. When reading the trends it will become apparent that human factors and technological developments influence each other in a bi-directional way. A reading guide (3.10) is included at the end of this chapter to visualise the relationships between the trends and the building blocks.

For all trends it can be said that they will all develop over a prolonged period of time. Therefore it is important to start preparing for these coming trends in time. It is recommended to act ahead of developments rather than start finding solutions at the moment the first problems related to new developments become apparent.

3.1 Information presented according to the operational role

3.1.1 The trend

Information will be presented in a more dedicated way to the needs of the role that the operational staff member is fulfilling. As such the way and sort of information presentation will be different for controllers (both ground and tower), assistants, etc.

It is expected that more information needs to be processed by the future operational staff members in the same amount of time. Especially information regarding the exchange of data with other stakeholders, surveillance data, downlinks from aircraft, safety nets, etc. will result in an increase of information (compared to the nowadays situation) that the operational staff member will be confronted with. Given the fact that human information processing capability has its limitations (see 4.1.6 for a model on information processing) the information must be presented in a more ‘tailored to the need’ way than today. One of the ways to accomplish that is to adjust the information presentation, even more, to the operational role that a person in the tower fulfils. Examples can be that alarms or warnings will be prioritized in different ways according to their relevance for a particular role, and that HMI is designed in such a way that the most relevant information will be more on the foreground (visual, auditory or even tactile). In aircraft cockpits this philosophy has already been applied successfully. To be able to design role specific information presentation, it is essential to identify the information needs of specific roles. In addition when replacing an existing system, it is necessary to understand all applications of this system to ensure new systems fulfil the needs existing systems fill (e.g. paper flight strips are used for planning, communication, building / maintaining situational awareness.)

Note that all relevant information will always be accessible to all operational staff and that the difference primarily is a matter of presenting it to the human operational staff member so that s/he will need less effort to process it.

Information need, and relevance of cautions / alarms will determine how information is presented to different operational staff members.

One of the examples of new tools in the future working positions will be situation displays (also called “user defined operational picture”) amongst others based upon the Advanced-Surface Movement, Guidance, and Control System (A-SMGCS). On these displays a geographic overview of airport and a/c and other vehicles is presented. Operational staff can give input to it, like with a digital strip, and dependent on different factors the exact information presentation, will be adjusted to the operator’s role and needs. For example warning for Runway (RWY) incursions can be given the controller who is in control of that particular RWY where an incursion is about to happen.

3.1.2 Influencing factors

The desire to exchange more information between the tower and increasing numbers of stakeholders and sources of information, and therefore the need for operational staff to be able to process more information in the same amount of time as nowadays makes that the current way of information exchange might no longer be sufficient for operational staff to deliver the same, safe and high-quality, performance. By adjusting the user interface, and information presentation, in such a way that one person can process more information with the same effort and in the same amount of time the operational staff will be prepared for this future demand.

To successfully integrate data from different sources, will require a different view towards “data”. The importance of meta information, identifying origin, confidence, security, etc., will increase. Originator identification and unique identifiers to match up pieces of data from different sources (radar blip, flight plan information, gate information, radio calls) are going to play an increasing role.

3.1.3 Comparison with current situation

In the current situation there already are differences in how information is presented. Basically each operator can choose which information (tables) s/he wants to see on the monitors (Electronic Data Displays - EDDs) on his/her working position. Function specific pages are available for the EDDs. In the new situation this diversification will be stretched further. Smaller details in tables or on screen will be presented in more or less pronounced ways depending on the role that an operator has.

For example, the weather forecast comprises information about likelihood that temperature and precipitation will result in slippery taxiways and ice on wings, while the same forecast also provides information about crosswind. Depending on the role in the tower these different sources of information are more, or less, relevant.

3.1.4 Opportunities and challenges

Opportunities

The information processing capacity, and the flexibility, of the tower (system and controllers combined) will increase. The advantage of that is that the operational staff will be better able to respond to the request for information from the tower, which will increase as well.

Operational staff will know better what goes on in other teams, and vice versa, as such they are able to adjust their communication and information exchange accordingly.

Challenges

Fall back scenarios in case digital systems fail will become more important when the tower will rely more on those systems. Important in this respect is to focus on so called “graceful degradation” of systems. This comes down to making sure that if a system fails it will not break down all at once but in different steps so that operational staff will have time and opportunities to still manage the traffic, possibly bring it in safe positions, before the entire system fails. In order to make graceful degradation happen not just technological solutions are needed but also care must be taken that the information that will be available to the controllers at the moment of failure is sufficient and comprehensible so that controllers will indeed be able to manage the traffic in such a manner. Note that this challenge is not limited to this trend but that it comprises most situations where technology is installed.

Operational staff may get used to the new ways of information presentation and they may rely on them. New generation of operation staff will have grown up with advanced technology and will generally have confidence in technology. In case the system fails operational staff must still be able to perform their tasks and be aware of everything relevant that goes on. Besides the graceful degradation care must be taken that operational staff will be knowledgeable and well trained about what to do, and not to lean completely on the new ways of information presentation, in case of failure. Also make sure that staff will still be able to understand and maintain SA, even if the system partly fails.

Note that an unintended side effect of huge amounts of information available to many persons can be persons interfering with each other’s tasks. Care must be taken that all this additional information will solely be used for the purposes that it was intended for. And that staff will not act upon other staff members’ tasks.

Another possible side effect is that if information is tailored to a specific operational role, being each other’s backup will be more difficult in a team.

3.2 Customisable and uniform working position

3.2.1 The trend

<u>Uniform equipment</u>

Like in other domains (even ordinary offices) working positions will become more generic so that persons can easily switch between work stations, and share work stations. Work stations will comprise a number of touchscreens, loudspeakers / microphones, and other generic devices and controls that all look alike when they are switched off.

More and more COTS equipment will be used at the tower. The customisation of tools for the operational staff will be in the software while standardised hardware will be applied more often. The trend to uniform and COTS equipment needs to be balanced with a trend towards more “nimble” software. As COTS equipment may be designed for shorter life cycles, and it is certainly stocked for shorter periods, maintenance replacement or replacement of failed units is often by necessity an upgrade to a newer display, computer or human interactive device. The operator needs to ensure sufficient ownership of the software used, so as to be able to transfer a platform to a newer version of the OS, accommodate peripheral devices with new (generally improved) specifications, etc.

There is also a tendency towards more open-source software. Not all components in the system need to be open source, but more and more the underlying libraries and toolkits for a system are in the open source domain. This also requires a degree of ownership/control that enables updating the applications to newer versions of the open source components. Rather than major deployment of new systems and long periods of minimal (mainly hardware) maintenance, incremental improvements and updates of systems will be more custom, in the form of virtually continuous investments in software updates and capability.

Operational staff can quickly and easily switch to another working station and combining and decombining will become easier and more efficient too.

Customisation to personal preferences

However, not all humans are the same, so every person has their own desires and needs regarding their working position. For example, some persons prefer to work in a quiet environment while others are stimulated by hearing the presence of colleagues. Technological solutions may be applied to give each operator the noise levels that s/he prefers. Just like in ordinary (open plan) offices, or like passengers in aircraft, or even passengers in cars, it will become possible to adjust a relatively uniform environment more and more towards personal desires.

This trend ranges quite wide. It comprises truly comfort related issues like personal settings for temperature and illumination. Hence, it also covers the devices to provide input to computers. Some individuals will prefer the old and flawlessly working buttons while others use computer mice, (haptic) touch screens or even Swype and voice input. When the working positions are uniform, this means that – for some functions – multiple input methods will become available.

The manner in which persons receive and access their information may be customized too. More and more information sources may be combined and merged and operational staff will be able to choose how they are able to look at, and compare, information. Some persons will prefer clear and individual tables for every information-item that they are interested in. Others may prefer the augmented reality in which they look at aircraft through the tower window while additional information about these aircraft is displayed on a head mounted display that looks like ordinary glasses.

Note that for all customisation and preferences the functionality of tools or technologies will not be affected neither will the way of working. It is just the preferences of the individual operational staff member and how s/he likes to access information and give input to the system.

Bring Your Own Device (BYOD)

Next to this customisation of the working position as it is offered by the employer, in this case LVNL, there will also be the development that employees will bring their own devices. People will be carrying more and more mobile devices like headphones, cell phones and tablets with them and organisations will integrate information exchange between “own devices” and ”organisation owned” devices.

The future working positions will become more flexible and customisable to a person’s personal needs and desires.

3.2.2 Influencing factors

A main factor to support uniformity, COTS equipment and the BYOD principle is costs. Dedicated equipment is and will be expensive in relation to COTS and BYOD. Further it is easier to replace standardised components when they break down. When new equipment is needed, for example because of updated technological demands, it is less expensive to adjust to these changing needs. An example is KLM pilots who often bring iPads with taxi maps in the cockpit.

Working in an environment that matches a person’s needs supports comfort and labour satisfaction. It may also lead to improved performance when people operate in an environment where they are comfortable and not distracted.

The external technological push is a factor of influence / relevance to take into account as well. Although the saying as ”if it ain’t broke, don’t fix it”, there are the technological developments, pushed by industry that force individuals and organisations to update both hardware and software. The most trivial example of this phenomenon is that older systems will not be supported after a while. This effect will, to a certain extent, also influence the choices that will be made when new equipment needs to be installed in the tower.

Systems used in the tower are often certified systems because regulations require that. As such regulations and certification will reduce the speed with which COTS and BYOD will be brought into the tower. On the other hand the COTS and BYOD trends will probably affect the regulations and certification themselves too.

3.2.3 Comparison with current situation

Nowadays equipment that is used in the tower often stems from official manufacturers who deliver their equipment dedicated for the purpose that it is used for in the tower. In the future a shift will be made towards more generic hardware. Further individual operational staff members will bring their own devices into the tower.

Standardisation will still be there, amongst others to ensure safe operations, though a trend will be that personal preferences of operational staff will get more impact on the ways of working in the tower.

3.2.4 Opportunities and challenges

Opportunities

Costs will be saved by this new way of working. This is a factor that gains influence more and more, also in the world of civil aviation. Further the job satisfaction of the operational staff members will increase when they can adjust their working station to their personal needs and preferences.

Flexibility regarding which working position to use, and how to alter that after (de)combining RWY's will increase.

Challenges

It is important to set priorities in the process of creating customisable working positions. After all there is really a great deal of choices and options in this domain. Therefore it is important to find out first what the most relevant aspects for customisation of workstations for controllers are and then to determine the ideal order of implementing them. As part of setting the priorities it is helpful to look for the foreseen effectiveness increase of the operational tower staff members.

There is a potential area of tension between operational staff members bringing their own devices, or using COTS equipment, with the current standards for tower equipment. Not all equipment matches with these standards. However, also in cockpits and in the military domain examples were found of an increased use of COTS, also privately owned, devices. Therefore a technological challenge is to integrate the different new devices flawlessly and to maintain safety.

When more COTS equipment is brought into the tower the question rises how much additional effort will be needed before this equipment can actually be used. A challenge is to find a guideline to indicate what kind of equipment should definitely be acquired as COTS and what should still come from dedicated manufactures. A relevant factor to take into account as well is the financial consequences. COTS equipment might be a cost saver, the price of dedicated software depends on many factors and needs to be studied in more detail before starting a migration process towards new technologies in the tower.

There is often less guarantee that COTS equipment can, for a longer term, be replaced or that spare parts available, so that potential risk needs to be included.

It may turn out that some operational staff members will end up with clearly contradictory preferences. Care must be taken that persons can select their preferences and at the same time do not hinder the other tower staff. For example, by selecting loud audio alarms for minor issues while the neighbour strives to create a neutral and as quiet as possible working environment.

When all operational staff members are able to set their own preference this could potentially lead to a situation in which the standardised way of working in the tower may be jeopardised. Care must be taken that only preferences can be set that do not interfere in a negative way with the normal way of working and procedures and operational task performance. This applies in particular for the shift handover. Nowadays a controller can watch his/her colleague for a while before taking over. This process needs to be adapted to the fact that the standardised way of information presentation will change.

Because every operational staff member has their own preferred way for information presentation the potential situation may arise that people are no longer alarmed in the same way for the same situation. This may have a negative impact on the shared situational awareness amongst the operational tower staff. Solutions to mitigate the negative side effects of this trend need to be found.

Some operational staff members may, due to their different preferences, look more often head down (or head up) than others. Care must be taken that this will not influence their situational awareness in a negative way. In other words, that no matter what the preference is, the quality of the information presentation may not be effected in a negative way.

3.3 Information integration

3.3.1 The trend

In fact two sub trends can be identified here. On the one hand information from different sources will be integrated in one display. On the other hand processing the information that is available into one coherent and meaningful manner is another way of information integration.

Underlying to the above mentioned user interface development where the focus is on customised user interfaces (either determined by role in the tower, or personal preferences), there is the need to create these interfaces based upon all kinds of information sources. The information coming from these sources will be integrated in coherent and useful presentation instead of the “one function per display” principle. Note that “sources” in this context splits in different stakeholders or parties at the airport but also that within each stakeholder more and more advanced technological systems will become available to provide information.

For example the information from A-SMGCS, digital strips, planning systems, radar and other stakeholders (incl. pilots) in the A-CDM process can be integrated in one coherent situation display. Such a system does not solely present information but it is also a data entry system. Or information coming from different systems owned by Schiphol can be delivered to the tower and be merged with information stemming from EUROCONTROL, weather forecast, etc.

Such an integrated situation display may be one huge monitor, though it may also (partly) be presented on different displays, a head–up display can be part of the integrated situation display. The same information is accessible in multiple ways. The integrated situation displays provides a coherent picture in a complete context. Though, for example, for controllers who are monitoring a RWY through the window it will be possible to see relevant information presented on a head up display, glasses, etc. as well.

An additional trend is in the type of information that is entered by the human operator into the automation and support systems. There is a trend toward interacting with the system at a higher level of abstraction, creating directives and goals instead of implementing change through low-level instructions. An example in case is the C-SHARE project (Paassen et al, 2013) – and more in general SESAR – where instructions to flights are by means of changes to the complete 4D trajectory plan, rather than by immediate speed and heading instructions.

In general it can be said that in order to support operational staff in the tower different information sources, coming from different stakeholders, will be brought together. This will enable that software tools (see Section 3.5) or even intelligent agents (see Section 3.6) will have access to all this information and be able to combine all the information in easier to interpret relevant chunks of information that the operator can quickly understand and process. Eventually resulting in the situation that less effort will be needed to combine and compare different information sources.

3.3.2 Influencing factors

The need to exchange more and more information with other stakeholders at the airport and the fact that different stakeholders ‘own’ different information sources is the main factor why integration is needed. After all, combining and processing information from different sources takes time. In order to handle the same amount of traffic and also to process the additional information an efficiency increase is needed. The need to exchange all this information is for example fed by A-CDM that is currently already partly executed at Schiphol.

All kinds of processes are handled in a serial manner. Information exchange enables to align different processes (inbound, outbound, en-route, etc.) better.

3.3.3 Comparison with current situation

Nowadays information stems from different systems, some owned by different stakeholders. And each stakeholder gets more systems that provide information. Some of those systems belong to airlines (incl. individual aircraft), others to the LVNL, EUROCONTROL or Schiphol airport, etc. All of these information providers present their information in a way that is relevant for their own operational staff. However, it differs from stakeholder to stakeholder whether they are interested in the same information at the same level of detail.

Currently information from those different stakeholders is presented in the tower at dedicated tools and displays. Therefore the information is often not presented in an ideal and integrated way for the different operational staff members.

3.3.4 Opportunities and challenges

Opportunities

Information integration (or even information fusion) by the system makes that the air traffic controller can process more information at the same time compared to nowadays. Without integration (or fusion), an increase in the amount of information and diversity of information sources would lead to an unacceptable increase in workload.

Because more information will be presented in a more, for the operational staff member, meaningful way the staff members can quicker and easier understand situations, and changes within situations and where these changes may lead to. As such the situational awareness of operational staff members will increase.

Challenges

To enable information integration, a prerequisite is that all stakeholders make relevant information available to the tower and vice versa. In addition integrated information should be synchronised and structured in elements, or a format, that allows combining them. For example when information from (infra-red) cameras will be combined with information stemming from radar there may be synchronization issues. It is a challenge to make sure that both sources will be integrated in one picture that is still meaningful to the tower operational staff.

Despite the advantages of being able to share information, there is also the risk that persons will interfere with other person's tasks just because they can, or have more information about the context in which the task is executed. To a certain extend the need-to-know principle or other solutions may be applied to make sure that the advantage of being able to share will not turn into a disadvantage. A guideline to handle this dilemma may be to leave the responsibilities for handling / acting with the persons (or systems) where they are.

This level of collaboration on joint information only works when there is a clear business case to be made for each of the stakeholder. Feedback should be clear and immediate, so that agents who have to provide the necessary data can see the results of their work.

It is recommended creating an environment in which scenarios can be tested off-line, in which effects of different 'treatments' can be verified.

3.4 Consistent human machine interface

3.4.1 The trend

With increasing complexity and increasing numbers of (support) tools and information systems the desire, or necessity, to streamline the information flow and to make it one consistent, or coherent, interface for the operational staff member grows. The HMI both encompasses consistent ways of human machine interaction and information presentation. Several examples exist of what such an interface could be like from other domains. Several different approaches are feasible. For example Airbus uses the dark cockpit philosophy=. Most important is that while redesigning the tower a single approach (philosophy, methodology) should be applied throughout all systems.

The most relevant information will be presented in the centre of the field of vision, while less relevant information will migrate to the periphery.

Also in the days when the flight engineer was removed from the cockpit, an important underlying design principle for the cockpit, that still applies, was the consistent interface both in information presentation as well as warnings, cautions, etc. The fact that all the work that is needed to fly an aircraft could be performed by a crew of two relied on this design principle.

The difference between this trend and the previous one (Section 3.3) is that in the previous trend the focus was on combining information in such a way that it becomes meaningful and comprehensible for an operator. Here, the emphasis is on presenting the same kind of information in the same consistent manner.

3.4.2 Influencing factors

The fact that operational staff members agree that more consistency is desired is a driving force for this trend. Also the technological feasibility of having all information available in a digital format and the freedom to choose how to bring that information on a display allows to be consistent. In the past the information presentation format as offered by the manufacturer of the equipment determined the level of consistency that could be accomplished. An additional factor was the fact that the tower has developed and grown over time. New tools were added at empty spaces, not necessarily at the most ideal location.

3.4.3 Comparison with current situation

Nowadays different systems are available for the operational staff in the tower. They are all implemented independently with as result that the entire working position becomes a bit complex and inconvenient. Such interfaces are proven error prone and also not comfortable to work in.

In the new situation all warnings, cautions and deviations from planning of comparable level of importance will be presented in comparable ways. Consistency of fonts, colours, audio signals, etc. will be applied. Not just from a perceptual, but also from a cognitive, perspective the information will be presented in a consistent way

3.4.4 Opportunities and challenges

Opportunities

The more information is presented to an operator, the more relevant it becomes presenting information in an easy and efficient to interpret way in order to maintain safety and capacity. This can be achieved by presenting information in a consistent and coherent way. Then operational staff can quickly, and with a minimum likelihood of being confused by the interface of a system, operate it.

Challenges

Some systems are LVNL in-house developments though to a certain extent the systems in the tower lean on existing systems from different manufacturers / designers. The challenge is to get all these systems aligned properly in HMI. Given the fact that generic (COTS) hardware will often be used, this challenge is primarily a software integration task. Partly this can be accomplished by having LVNL staff designing and implementing the software and partly by providing instructions / demands to manufacturers of software and tools to provide user interfaces aligning with the user interface design philosophy that LVNL has embraced.

It will take several steps or iterations to migrate from the current situation to a totally new situation. It is no option to remove all the equipment that is installed at the tower now and replace that all at once with new equipment. Therefore an implementation philosophy, about how to make such a transition happen over time, needs to be developed.

The location where information will be presented is also a factor to take into account when designing a consistent interface. Consistency is needed in which information will be presented directly in the centre of the field of vision and what information can also be placed in the periphery.

3.5 Support for human sensors

3.5.1 The trend

It is foreseen that the Schiphol airport will grow. Growth is more than just an increase of the number of aircraft that is handled. Growth comes together with more passengers, more luggage and cargo and therefore more buildings, piers, gates, taxiways, aprons etc. As a result the operational staff in the tower will face more areas and aircraft that need to be monitored. Additional sensors to support the operator’s naked eyes (to see things that cannot be seen straight from the tower anymore) will become available.

Cameras, including infra-red cameras, will be used to monitor aircraft on taxiways, aprons and at gates. The cameras will film the aircraft and other vehicles. When needed there will also be intelligence added to the camera image. There will be the opportunity to actually track aircraft automatically. The images will be merged with information coming from other sensors, like ground radar, data bases, etc. Controllers can easily note and identify aircraft and vehicles, see their intentions, and also look behind buildings, possibly monitor the Polderbaan (18R - 36L) from the main tower, etc. This is especially so due to the fact that information will be integrated in an intelligent way. Therefore it will not take more time (compared to the current situation) to process all the information coming from all these different sensors.

The additional sensors will allow for certain operational staff members to have their working position in another location. Possibly not all controllers need a position in the tower at the visual control room. Due to the support for sensors and improved communication means and means to access shared information (for example through A-SMGCS).

3.5.2 Influencing factors

Given the fact that growth will continue and that growth comes with additional infrastructure that might block the view from the tower, solutions need to be found to enable operational staff to be able to see everything that is relevant.

The opportunity to create huge databases (big data and data mining) to share with other stakeholders at Schiphol airport allows exchanging intentions of these stakeholders. Availability of these intentions may also be used to augment real time information from the different kinds of cameras at the airport.

Also the availability of new technology and the fact that it can be applied (like for example the remote tower project that solves all kinds of problems (perspective, all weather conditions, etc.) related to using cameras to replace the view of the naked human eye from the tower) may be a reason in itself why new technology gets installed.

3.5.3 Comparison with current situation

Currently there is the situation that, around the Quebec taxiway at Schiphol, buildings block the view from the tower. When this trend progresses the necessity to enhance the view (with or without additional sensors) increases.

Right now cameras are already applied to monitor parts of some piers that are hard to see direct from the tower (TWR-C) In addition is study is performed on how to use cameras to replace an observer at night for TWR-W.

Airport capacity is to a large extent dependent on the visibility conditions. In low visibility conditions the safety margins are increased, resulting in a lower throughput. Any measure that can help alleviate the low visibility capacity reduction is helpful.

3.5.4 Opportunities and challenges

Opportunities

An opportunity is improved monitoring of all movements and statuses at and around the airport. Sensory support can aid the human in situations where human perception is not sufficient or when a combination of sources of information provides added value to perception only. This allows the operational staff to be more in control and better able to respond adequately and timely to new developing situations that require interference from the tower. State of the art remote tower technology provides opportunities to further develop sensor technology that can be used to support human vision.

Challenges

Currently a great deal of research is done on the remote tower. This research can be a source of inspiration. It has already solved a number of issues that exist regarding implementation of camera’s to monitor traffic. It also brings potential risks and problems under the attention and it can provide an overview of the potential risks, problems but also benefits that may result from applying remote sensors to support the human operator. After all some issues that may arise from growth at Schiphol will have certain (technical) similarities with the remote tower work.

Nonetheless issues like maintaining situational awareness, being able to see aircraft and surrounding environment in the right perspective, impact of poor visibility conditions need to be solved before making the extra sensors operational.

Care must be given to identifying precisely for what situations, numbers of vehicles, etc. this support for human sensors is a realistic solution. For example, a solution can be applying sensors only for those situations in which no actual separation of aircraft is required (e.g. monitor whether a gate is occupied, or monitor whether unwanted, potentially risky, objects have appeared in the vicinity of a RWY).

Enhanced and supported view, with cameras or virtual reality needs special attention to “visual momentum” (Woods, 1984) . The different information views, whether alternating on the same display device or presented in parallel, need sufficient anchoring information to enable users to quickly navigate and to prevent users from getting lost.

Finally, there will be regulation related challenges. For example ICAO doc 4444 states “control of aerodrome traffic is in the main based on visual observation of the manoeuvring area and the vicinity of the aerodrome by the aerodrome controller”. The challenge is to make all these additional sensors compliant with current ICAO regulations, which needs to be worked on.

3.6 Automation philosophy

3.6.1 The trend

After “integration of data streams” and “information presentation according to what is needed for an operational role” a next step is automation. More tasks will be automated. Automation can be done at several levels and a very relevant question is what will be automated, and until what level.

Men will be doing those tasks that they can do better than automation, while automation will focus on those tasks that that automation does better than the human operator.

A rough guideline can be to make automation dependent on the uncertainty, or potential risk, that is related to the function that may be automated: the lower the risk the higher the level of automation and vice versa. See also Sections 4.1.1 and 4.1.4.

Another rough guideline is that the more tactical and less strategic / planning-related a task is, the less likely it will be that the task can be automated within the timeframe that is covered by this vision.

Also for tasks for which it is relatively simple to predict how they should be performed (tasks that can be described as clear rules) it is relatively simple to automate them and that will primarily make the operator’s life easier.

Specific kinds of automation are the so called “adaptable” and “adaptive” automation. These concepts refer to automation that acts at a higher or lower level dependent on what the operational staff member chooses, or even dependent on the mental state of the operational staff members as assessed by the automation itself. It is foreseen that in the long run adaptive automation might also be introduced to the tower, though for the time frame that is covered by the current vision the adaptive automation will have to mature further and will only to a limited extend be applied in the tower. By limited is meant that not all theoretical possibilities to let software assess the mental state of the operational staff member will be used yet.

3.6.2 Influencing factors

The growing flow of data that needs to be processed by the operator will, just like for other trends, be a main factor why more automation will be introduced. There is a great deal of resemblance with the situation that the flight engineer was removed from the cockpit since most of his/her tasks were replaced by automation (4.1.5).

Also there is probably the cost factor. Once machines are able to do certain tasks equally well as humans and they are cheaper, then this work will probably migrate towards the machines. This is also in line of the European guidelines for automation, namely automation contributed to increase safety, reduce environmental footprint and reduce costs (4.3.1)
New generations of operational staff members will also be used to a broad variety of communication means. This will enable them to use chat, video conferencing, etc. as a natural way to communicate with individuals or entire teams in an effective way. They will be used to these communication means and will even expect them to be available in the tower. (see 4.1.2)

3.6.3 Comparison with current situation

Currently computers and automation are already in place at the tower. The main difference with the current situation will be that due to the fact that more data will have to be processed, there will also be more data that will be processed automatically. The other difference is that automation will become more sophisticated, or the level of automation will increase.

3.6.4 Opportunities and challenges

Opportunities

Just like the other trends described above, the increased workload for the operator, resulting from additional information to process, will be mitigated by the automation that will take some load of the operational staff members' shoulders. When introducing new automation not only the usability and efficiency of automation should be taken into account but also the satisfaction of the user with the automated system. Only satisfied users will comfortably use automation and thus trust the system with loosing decision making competence (see also 4.1.3).

Challenges

The tasks that are easiest to automate were the tasks like “provide a warning when certain thresholds are exceeded”. Such tasks come down to straightforward rules that can relatively easily be described, and therefore automated.

In the cockpit the level of automation has increased with as result that monitoring became a more relevant aspect the pilots’ tasks. It may be relevant to focus on the lessons learned from this domain when increasing the level of automation in the tower.

The suitability for automation of tasks or parts of a task is related to the distinction between more “open” and more “closed” systems, as presented by Vicente (1999). A closed system in that respect is a system with a limited and countable/measureable interaction with its environment. It is possible to automate the operation of such systems because their inputs and outputs can be measured and quantified. An open system is characterised by many, varied and often poorly quantifiable interactions with the environment, and as such defies automation and needs human control.

The National Research Council of the US has provided a rough indication that for system functions with relatively little uncertainty and risk a high Level of Automation is appropriate. However, when the system function is associated with greater uncertainty and risk, the Level of Automation should not be more than ”the computer suggests an alternative”. And added: “Any consideration for automation at or above this level must be designed to prevent: loss of vigilance, loss of situation awareness, degradation of operational skills, and degradation of teamwork and communication. Such designs should also ensure the capabilities to overcome or counteract complacency, recover from failure, and provide a means of conflict resolution if loss of separation occurs”.

3.7 Intelligent agents

3.7.1 The trend

The tower staff will be complemented with intelligent agents. Agents are in fact software tools, a dedicated kind of automation, which will support the individual operational staff members and the teams at the tower. They may even support the larger teams like the stakeholders who need to collaborate in the context of A-CDM.

Agents are goal oriented (whereas automation in general not necessarily strives towards accomplishing a particular goal) pieces of software and will act according to how a situation develops. The agents will be able to collect data from different sources or stakeholders. The agents will have some "intelligence" and will do more than just present information. The agent can check information for abnormalities or suggest solutions to the operator. Because the agent can monitor the operators inputs, the agent can adjust its information presentation to the operational staffs' needs. Agents are especially good at monitoring small seemingly insignificant changes, and to monitor those continuously without being distracted by other (sub)tasks. An example can be an agent that monitors all traffic in approach and informs the operator when an aircraft tends to deviate too much from the planned path and situation. How the agents informs the operational staff member can be made dependent on the circumstances and how they develop.

3.7.2 Influencing factors

A-CDM will require from the tower that tower staff will take into account all kinds of issues, factors, information and statuses from different stakeholders outside the tower. This enormous information flow can to a certain extent be managed by agents (automation). By doing so no additional staff will be needed to monitor and process all that information. The agents can become team members without the need for a physical working position in the (small) tower. Due to the expected growth in traffic foreseen by SESAR (4.2.1), air traffic control will have to handle more aircraft. To keep workload within reasonable levels, tasks need to be redistributed between team members or the team size needs to be increased with either humans (that need a working position) or intelligent agents (that need no working position). Since it seems that agents have and will, over the years, become more full and valuable assets to teams.

3.7.3 Comparison with current situation

The most important difference with the current operation is that some (parts of) tasks that are currently performed by humans will be done by agents instead. Nowadays all decisions in the tower, also the less critical ones are made by humans and all monitoring of the situation and checking for abnormalities is done by humans. Even though agents have their limitations, they do have some monitoring capabilities where they excel human operational staff. The Man Are Better At – Machines Are Better At (MABA-MABA) lists, that were made by many authors, indicates the importance to determine very well were automation (agents) should be involved and what tasks should be left solely to the operator. In general terms one can say that the more critical a decision is, the more important it is that a human stays in control. Especially for planning tasks that are related to longer term processes an agent can be a useful assistant.

Future operational staff in the tower will be more accustomed to computer systems operating at higher levels of automation. As such the confidence in such a system will, just because of their previous experiences, probably be higher than it would be when the system was introduced to the nowadays tower operational staff.

Thrust between human operators and automation has been extensively studied by Lee and Moray (1994) and Muir (1987). Preferences, but also experience of the operator and the perceived reliability of software or software agents play a large role in a dynamic relationship between trust, reliance and performance.

3.7.4 Challenges and opportunities

Opportunities

Agents can be seen as additional means of improving human capability. The agent is in fact one step further than a user interface that is adjusted to an operator's role. The agent does not bluntly present information in a way that is relevant for the role. It also monitors the information for aspects that are relevant to know for the role, it monitors the information in a goal oriented way and it may learn or use information in order to achieve its goals. It does this in a more subtle and complex manner than ordinary software tools do and that discriminates that agent.

Challenges

In order for agents to participate in the operation they need access to a great deal of information. This information is hard to get and interpret when based on non-digital forms of information such as paper flight strips or spoken (radio) communication. From this follows that digitised information, like digital flight strips communication via ICT (e.g. datalink) and integration with other information systems is of utmost importance. After all when a substantial amount of information cannot be made available to the agents, they cannot deliver to their full potential. Data mining is a possible mean to provide pre-analysed and –categorised chunks of information, which is readily usable for intelligent agents.

Working together closely with a system that acts in a more intelligent way than what people are used to from conventional systems, requires a new perspective on human-machine interaction.

Operational staff is in control (4.1.1), from this follows that they should always consider agents and automation as support tools, and not as systems that they can always blindly rely on. The workshare between agent and human operator must be unambiguously clear and the human operational staff member must always be able to overrule the agent.

In the eighties most civil cockpit crews were reduced to crews of two persons (4.1.5). The flight engineer was removed from the cockpit. This could be done because the tasks of the flight engineer were analysed and broken down in smaller components. It turned out that these components could each be replaced by automation. This approach provided knowledge about the feasibility of the operation before implementing it. It is recommended to learn from this approach when determining which tasks can be performed by agents and which should be fully controlled by a human operator.

Software agents, because of their focus on a singular purpose, often display “emergent behaviour” through their interaction with the environment. Creation of a “specification” for the function of a single software agent is thus not straightforward and not sufficient for success. The agents need to be evaluated in combination with each other and the system or domain they are acting on to verify that the emergent behaviour of the combination is desirable.

3.8 Shift from tactical to more planned operation

3.8.1 The trend

A foreseen change is that planning and anticipation will determine more and more how operations will be executed. There is EUROCONTROL and SESAR (4D trajectory planning) that will ask for very accurate planning and timing for departing and arriving aircraft. Further there is the need for increased efficiency at the airport, for example induced by A-CDM. The operation will become more time-based and inbound, turn-around and outbound processes will be coupled closely. On top of that there is the, above mentioned, increased flow of information that needs to be processed and produced. And finally there are changes of RWY configuration that are also influenced by factors outside the control of the tower. By using the right information it will be possible to better predict in advance what these changes will be like. Therefore it would be very relevant and efficient if operational staff has improved means and opportunities to anticipate and plan. Operational staff in the tower will be more involved in data management. This is trend that can also be seen in cockpits both in the civil as well as the military domain.

In the enormous data streams that will develop, not just the data that are instantly available, but also the data gathered over a longer period of time, will allow data mining, to recognise patterns and to use that integrated knowledgebase to plan new operations. Examples for these data streams are trends in weather, airline preferences, traffic patterns, deviations from schedules under particular circumstances, etc. The data mining techniques will bring patterns to the surface that were never identified before. These patterns can be used to better predict deviations from the operations in advance and agents will be able to use that information to propose changes to the operation. Here too digital flight strips will allow to gather information from the tower and to combine that with the other data streams.

Finally warning systems will be available, not only for last minute changes or characteristics of the actual (current) situation, but also for situations that are expected to develop in the (near) future. For example, based upon those data analyses, warnings can be provided for flight schedules that do not match and will have their effect over longer periods of time.

3.8.2 Influencing factors

Because of increased collaboration between teams and organisations, operational processes will become less stand alone and more dependent from each other. Making decisions not only impacts the operational process for which these decisions were made, but have a more widespread effect. A need for a less ad-hoc and more planned operation emerges, so that all involved parties are timely involved and can anticipate on each other’s situation.

3.8.3 Comparison with current situation

Taken it all together the increased amounts of data will allow planning more accurately and longer ahead at the same time. The operational staff will be more preparing, based upon huge quantities of data stemming from LVNL databases but even more upon the life data streams that follow from the A-CDM stakeholders and EUROCONTROL. The planning will focus upon what the best way to maintain the traffic flow will be. Once the planning is done properly, there will be fewer deviations that need to be acted upon at a tactical level. So roles will change from more operation according to the plan and less tactical.

3.8.4 Opportunities and challenges

Opportunities

By being able to better predict in advance what will happen, and to adjust operations accordingly, will be appreciated by customers. Customers in this context can be airlines, airports, different stakeholders operating at airports, EUROCONTROL etc. All of these players will be able to plan their own operations more efficiently since Schiphol is more predictable. Systems like automated take-off, landing will support more precise planning possibilities (4.4.1). By offering customers a better predictable operation they can plan their operations better too and that will make them more satisfied customers.

The predictions can be used for example for improved planning of the use of resources, based upon how situations (will) develop. Related to that is that workload can be managed better because high workload situations can be better predicated and anticipated upon.

Challenges

Gathering all data that are needed is challenging and bringing them altogether in a meaningful way even more. New information presentation techniques / user interfaces, intelligent agents and digital strips are all prerequisites to use the enormous amounts of available data in a meaning full way.

Note there will always be last minute interferences with planning; for example blocked run- or taxiways, calamities at the airport or really unpredictable changes of weather.

3.9 Increased teamwork and more flexible teams

3.9.1 The trend

Teams will grow and teamwork will become more important. The already existing teams, for example operational staff in the tower, will still be there, though new intense ways of collaboration between different operational staff members in- and outside (for example, Area Control Centre (ACC), approach, or teams operating at the apron or near the gates) of the tower will develop. In a way one can say that new, and rather flexible, teams of frequently changing composition will be created.

Due to improved means to monitor what goes on at the airport (see Section 3.5) some operational staff members who are nowadays operating in front of a window in the tower, can move to other physical locations at lower floors inside the tower, or even outside the tower. Augmented reality and new innovations as swyping will further improve interactive teamwork.

As a result the communication between team members will change. It will not always be possible to physically look another team member in the eyes. So new means for effective communication over longer distances will be introduced and communication in general will change. As such communication will also become more silent and digital, and less via radio or face to face. CPDLC is a first step toward voice-free communication.

Since agents will become part of a team (either tower staff or a larger team) the teamwork will be affected as well. Agents have different ways of communicating than human operational staff does. Agents cannot be spoken to, just like a human team member sitting next to each other.

With these agents there will be less informal information exchange, and less information exchange by voice. After all, the agent is located inside the computers in the tower. As such the agent as team member will primarily be a software tool and will not have an appearance like human operational staff, robots, or anything else that can be physically touched.

For the larger teams it will be so that team members will all have their own information available regarding situations that comprise the entire team. For example in aircraft the taxi-navigation software may provide pilots with information about movements of other traffic. This knowledge may influence how pilots will communicate with the tower.

3.9.2 Influencing factors

Today's operational staff members were raised in a world in which automation was relatively new, and in which the human is always in control of everything. They are not used to fully relying on systems operating at higher levels of automation. A number of the trends that are being described here will actually be implemented in a timeframe of one to possibly several decades from now. In that time frame a different generation will be operational in the tower. This generation will be used to relying on higher levels of automation, also because the quality (stability, capacity, decisions made) of automated systems will increase and justify the increased confidence of human operational staff in these systems.

A new generation of operational staff members will also be used to working together with actors- being humans or computerised agents – that are not physically in the same room (they are e.g. used to virtual classrooms). Also, they will be used to work in teams that comprise both human and virtual agents. These situations already exist in current day's computer games and will evolve rapidly.

Developments like A-CDM and other efficiency enhancing techniques that will involve a great deal of collaboration and communication will induce that new teams, as described above, will be formed.

3.9.3 Comparison with current situation

Nowadays the operational staff in the tower can be considered one team. Stakeholders operating outside the tower are other teams. In the future, these teams will still be there, though there will also be new intense ways of collaboration between different operational staff in- and outside of the tower. Because of the physical distance between the team members of these teams, and the enormous amounts of information that can be shared via databases and computers, new ways of information exchange between team members will develop.

3.9.4 Opportunities and challenges

Opportunities

To collaborate effectively without the necessity that team members need to be physically on a close distance and that team members need to be human.

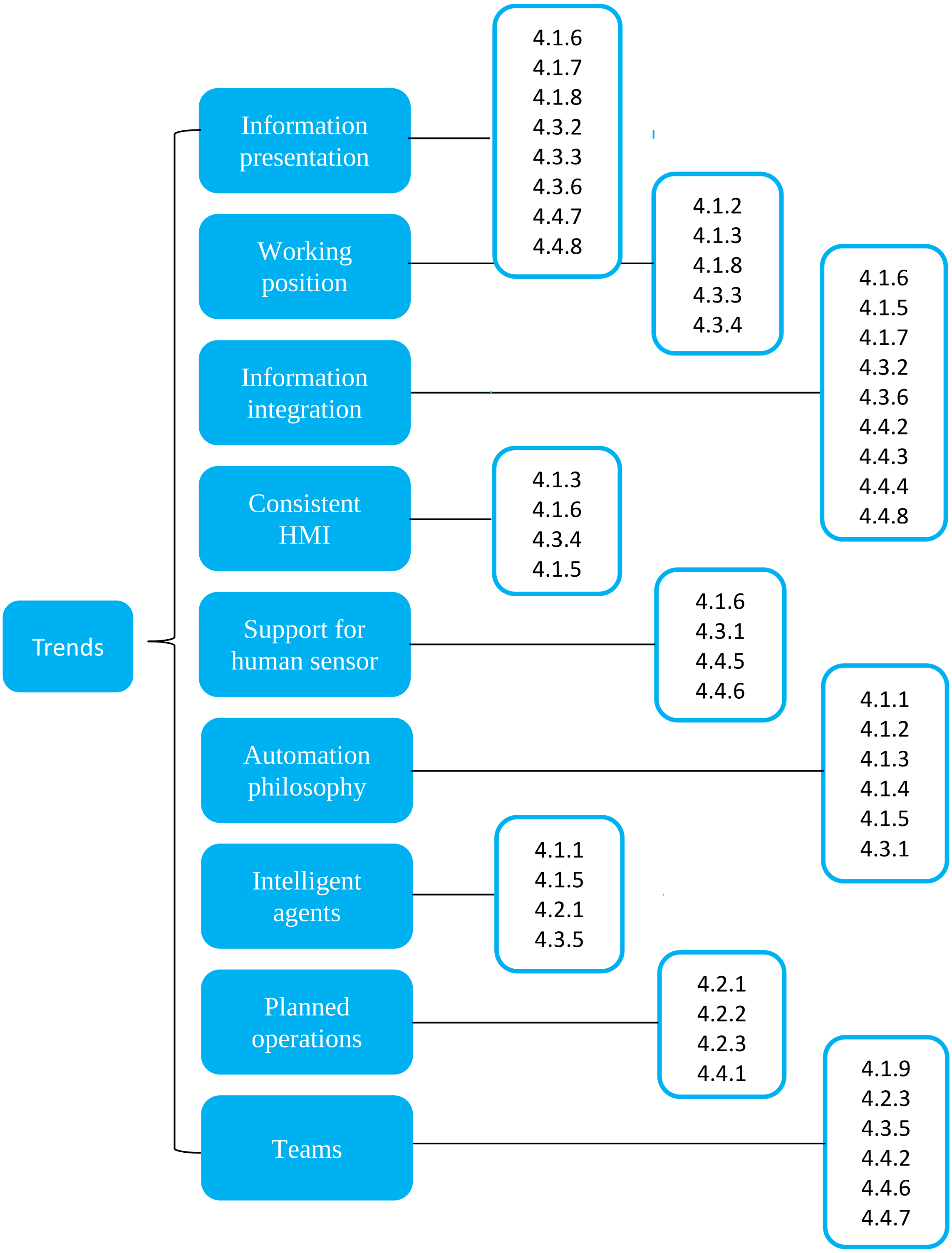
Challenge

Find ways to communicate as effectively as nowadays over longer distances, also with team members of (last minute assembled) flexible teams who don't know each other so well as the teams as we know them today. Communication is often more than just words, new easy and fast to use techniques need to be identified to express non-verbal behaviour. Even more challenging is to that with intelligent agents as parts of the teams.

Different team members from a larger team will all have information about the same situation, and as such may act upon that information by themselves, rather than allowing the responsible operational staff member to take the action. Care must be taken that persons will not make their own decisions, but that team plans, tasks and roles remain respected by each team member.

3.10 Reading Guide

This reading guide shows the relationships between the trends described in this chapter and the background information presented in the following chapter. By clicking on a paragraph number the reader is redirected to the related paragraph in Chapter 4.



4 Developments and background knowledge

In this chapter the building blocks for the trends from Chapter 3 and the vision described in Chapter **Error! Reference source not found.** are presented. These building blocks are derived from running and completed research projects, scientific literature, other sources such as news reports, and the knowledge and experience of LVNL's (operational) staff and NLR's staff.

A number of the examples stem from different domains then ATC, for example military and civil aviation, or even design of mobile phones. This is done to underline that the trends that are described in Chapter 3 also, to a certain extent, take place in other domains, or have taken place in other domains. These example are supposed to support the fact these trends will take place in the tower as well.

4.1 The human role

4.1.1 Responsibility of the ATCO

The ADAHR project – Assessment of Degree of Automaton on Human Role – is a European research project that looked into the influence of different levels of automation (see Section 4.1.4 for a description of the levels of automation) on future ATM related roles and responsibilities within the Single European Sky. The levels of automation studied were Level 2 (*The system offers a complete set of decisions/action alternatives*) and Level 5 (*The system suggest one alternative and executes that suggestion if the human approves*). The ADAHR project team concluded that a higher level of automation is acceptable for the human as long as the human has some understanding of the reasoning process of the system. Transparency of the system, i.e. insight in information sources, the prioritization rules, and the involved parameters, is essential to achieve acceptance and trust.

A lack of system understanding can have two major negative implications. First, a lack of understanding can lead to higher levels of mental workload if the human tries to make sense of the system's reasoning. This requires mental capacity and also distracts the human from primary tasks. The sense making process intensifies with specific personality traits. For example, individuals with high conscientiousness and technology suspiciousness feel more need to understand the system compared to quick decision makers and technology savvies (Roos et al, 2013). Second, a lack of system understanding can result in a "dull operator", who simply accepts an alternative as presented by the system. In this case the human mind, reasoning, and critical thinking have no additional value, which is an undesirable situation as long as no real intelligent systems exist.

In summary, from a human perspective higher levels of automation are supportive of the human task if the human has control about the final decision, some understanding of the system reasoning (transparency), and sufficient trust in technology.

Similar conclusions have been drawn by the C-SHARE project (Cognition through Shared Representation; Maij et al, 2013 and Paassen et al, 2013)). C-SHARE takes a closer look into how to match the solutions proposed by a system with the expectations of radar air traffic controllers. The joint cognitive system aims to present travel space information to support ATCOs to “(visually) re-plan air traffic within the performance, timing and separation constraints prevalent from the work domain” (Maij et al, 2013). The basic assumptions include that a successful system needs to keep the human in the loop. This means that the human must understand the information presented by a system in order to interpret the information correctly and anticipate on future situations. Moreover, comprehension about the reasoning of the system is essential to handle system failure. These basic assumptions let to concept of a joint cognitive system design, which is highly accepted by the ATCOs involved, as studied in a human factors experiment. Although the C-SHARE system would change the nature of the ATCOs somehow, ATCOs reported that their work would not become less interesting and that they still feel fully in control. These results imply that Level 3 automation (*The system narrows the selection down to a few*) is feasible and desirable in the future, when taking basic assumptions about human factors requirements into account.
In the Mufasa project (Westin et al, 2013), the necessary compatibility between automated solutions and human preference was explored more in-depth, through a series of human-in-the loop experiments.

4.1.2 Future generations of employees

In 2030 the majority of ATCOs consists of individuals who have been born in the mid 90ies or later. They are called generation Z or “GenZ” and sometimes “iGeneration”, and they are often described as digital natives and Internet savvy (Roos et al, 2013). These individuals grow up in a global and fast-paced world with highly sophisticated information and computer technology.

While yet not much is known about the needs and skills of young generations in the occupational world, the social, technologic, and economic environment (e.g. job security) typically influence these needs and skills. For example, it is assumed that GenZers will quickly and easily select and process information from various sources of information since they grow up in a world of information abundance. Information overload could become an issue if they have not developed effective selection strategies. Moreover, GenZers might easily become bored by single tasks and are able to switch among multiple tasks. This, however, may result in relatively small attention spans compared to current generations. GenZers presumably accept and appreciate high levels of automation but are consequently less critical towards the quality and reliability of automated information. In addition, they are used to electronic communication (rather than voice communication), and may have rather idiosyncratic goals resulting in a preference for individual work instead of teamwork. Due to the possibilities of technology GenZers assume that work can be carried out from everywhere and whenever – time and location is not a critical factor.

These assumptions about future generations, which will define the pool of employees in 2030, can help to design an ATM-system that takes the strength and weakness of future ATCOs into account. Higher levels of automation will be accepted, as well as less personal contact mediated via technology. This creates opportunities but also the need to introduce advanced automated systems in ATC.

4.1.3 Comfortable for the human

Up until recently, a human-centred design approach was predominantly focused on guaranteeing effective and efficient human machine interaction. The subjective aspects of human machine interaction were recognised (see Figure 1) but in practice treated as less important (see for example: ISO 9241-11). Effectiveness was principally a measure of the amount of tasks users could complete with the system, while efficiency was often expressed in task completion times.

Usability	The effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments.
Effectiveness:	The accuracy and completeness with which specified users can achieve specified goals in particular environments.
Efficiency:	The resources expended in relation to the accuracy and completeness of goals achieved.
Satisfaction:	The comfort and acceptability of the work system to its users and other people affected by its use.

Figure 1. Usability as defined in ISO 9241-11.

With the rapid growth of internet based consumer services and app ecosystems on smartphones and tablets, the importance of the subjective aspects of usability has grown. Instead of guaranteeing usability, many design efforts are nowadays aimed at delivering a favourable user experience. User experience (a.k.a. UX) involves all of a person's behaviours, attitudes, and emotions about using a particular system. The traditional usability aspects of effectiveness, efficiency and satisfaction are a part of UX. According to the recent ISO 9241-210, user experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use. Stated in a different way: while usability refers to the question “can users reach their goals with the system?”, user experience adds the question: “how delightful do the users feel about using the system?”. Thinking about user experience instead of (solely) usability emphasises to also consider issues as work organisation, job design, the working environment, and training and support.

4.1.4 Higher levels of automation

Increasing parts of the decision making process may become (more) automated in the future. Actually, coinciding with the strong growth in the use of smart devices (tablet, smartphones), higher levels of automation are already getting more common for everyone’s daily routines. The tasks, which the human(s)-automation-system should perform, should be divisible in functions (information sensing, perceiving, deciding, acting). The Level of Automation (LoA) depends on the number and type of functions allocated to the human(s) or the automation.

The LoAs range from starting with automatic information collection, option generation, subsequently automatic option prioritisation, automatic evaluation of options, until eventually automation of option choice. Several taxonomies for LoA exist (see Figure 2 below). In all taxonomies, the different levels correspond to how much freedom the computers get to make decisions, or how many decisions that nowadays are made by humans will be made by computers in the future. The technical feasibility to reach these higher LoAs and how ATCOs may deal with the LoAs are relevant issues for the new tower to take into account.

A frequently used classification of LoAs stems from Parasuraman, et al (2000) who proposed a set of ten levels of allocation of decision-making tasks between humans and computers (see Figure 2).

1. The computer offers no assistance; the human must make all the decisions and actions;
2. The computer offers a complete set of decision alternatives;
3. The computer narrows the selection down to a few;
4. The computer suggests an alternative;
5. The computer executes the suggestion if the human approves;
6. The computer allows the human a restricted time before automatic execution;
7. The computer executes automatically, then necessarily informs the human;
8. The computer informs the human only if asked;
9. The computer informs the human only if it (the computer) decides to;
10. The computer decides everything and acts autonomously, ignoring the human.

Figure 2. Parasuraman's Ten Levels of Automation.

Other categorisations as described by Endsley and Kaber (1999), come down to the same principle, namely that one can make quite explicit what the borderline is between who is in control, and until what level, the human or the automation. Bruni et al (2007) state that it is important to take into account, when actually creating a system in which a LoA is chosen, to be sufficiently clear for the user who is in control in order to maintain mode awareness and avoid automation errors. Especially difficult in this respect are adaptable systems, since they adjust their LoA constantly dependent on developments in environment and user.

In the US, the National Research Council (NRC, 1989) recommended that for system functions with relatively little uncertainty and risk a high LoA is appropriate. However, when the system function is associated with greater uncertainty and risk, the LoA should not be more than ”the computer suggests an alternative” (approximately level 4 in Parasuraman’s taxonomy). The panel adds to this recommendation of the NRC (1989) “Any consideration for automation at or above this level must be designed to prevent: loss of vigilance, loss of situation awareness, degradation of operational skills, and degradation of teamwork and communication. Such designs should also ensure the capabilities to overcome or counteract complacency, recover from failure, and provide a means of conflict resolution if loss of separation occurs”. While the NRC recommendation is several years old, the principles are still applicable to today’s developments in automation.

In case the level of automation is selectable, two main types of automation strategies are possible: adaptable automation and adaptive automation. In case of adaptable automation, the automation level is set by the human user. In case of adaptive automation, the automation level is set by the system based on measures of performance and/or cognitive state of the system user. The latter has been researched extensively for several military high task load applications, but adaptive systems based on measures of cognitive state have not (yet) been put into practice.

The main challenge is to effectively reason about human behaviour and to deduce if and what kind of support is needed.

4.1.5 Automation in the cockpit

The introduction of the 2-crew cockpit in the 1980ies constitutes a successful example of automation in aviation and profoundly changed the human role in the cockpit. The 2-crew cockpit included that the tasks of the flight engineer were replace by an automated system. The tasks of the flight engineer were (a) operating the aircraft system under normal and abnormal situations, (b) reading and executing check lists, (c) extracting take-off and approach data and engine power settings, (d) carry out in-flight testing and fault analysis, and (5) recording system defects (Hillman & Wilson). Although there were many concerns about replacing the flight engineer by automation, such as the lack of a third pair of eyes, unreliability of the automated systems, and high workload for the remaining crew in case of non-nominal situation, the 2-crew cockpit have not led to a decrease in safety or unacceptable high workload conditions.

Two main reasons may be given for the successful automation of the tasks of the flight engineer in the cockpit. First, the work of a flight engineer primarily included tasks, such as calculations or extracting information from large datasets, that can more reliable and quicker been carried out by a machine than a human. Second, technologic advancements provided possibilities to present aircraft system information to the remaining crew in a clear and situation-driven way. Thus, the crew could access relevant information, which was previously presented only to the flight engineer, just in time and integrated with their existing cockpit systems.

These two reasons for successful automation of the tasks of the flight engineer can be generalised to two lessons learned. Namely, that it is important to automate those aspects of a task that are challenging and error-prone for a human, but not a machine, i.e. simple cognitive competences; the second lessons learned regards the need for an adequate human machine interface with effectively integrated information. Automation is usually associated with more monitoring activities for the human, a task humans are typically bad in. Therefore, if possible information must only be provided, i.e. made visible in a comprehensive and integrated manner, when attention from the operator for this specific task is required.

The introduction of the 2-crew cockpit was only the beginning of automation in aircraft systems. Today's 4^{th} generation transport aircraft are highly automated systems, with high levels of reliability and rare occurrences of unexpected events. However, as the task and responsibilities of the crew are gradually transferring from actively flying the aircraft to system monitoring, pilots find it difficult to switch to manual control if the system unexpectedly fails. Pilots are often surprised and confused in such situations. These issues are currently addressed in the Man4Gen project (e.g. Rankin et al, 2013), which studies the reasons why pilots react surprised and confused in flight under particular conditions. Man4Gen investigates the effects of these mental states on the ability of pilots to manually fly the aircraft and make active and authoritative decisions in unforeseen situations.

Man4Gen found that particularly the state of confusions, which arises from the unexpected situation and surprise, is a threat to pilots' performance. Confusion can result from conflicting information of the system and the real world. Unclear so far is whether pilots have sufficient in depth system knowledge to handle unexpected situations. Opinions vary with regard to the amount of knowledge necessary to deal with surprising events.

4.1.6 OODA loop

The OODA (observe, orient, decide, act) loop is a conceptual model to explain human information processing, behaviour, and learning processes in complex situations. It was originally developed by John Boyd (Osinga, 2005) in the context of combat operations to describe how to direct one's energies to defeat an adversary and survive. Since then, it has also been applied in other domains, such as in increasing the effectiveness of organisations.

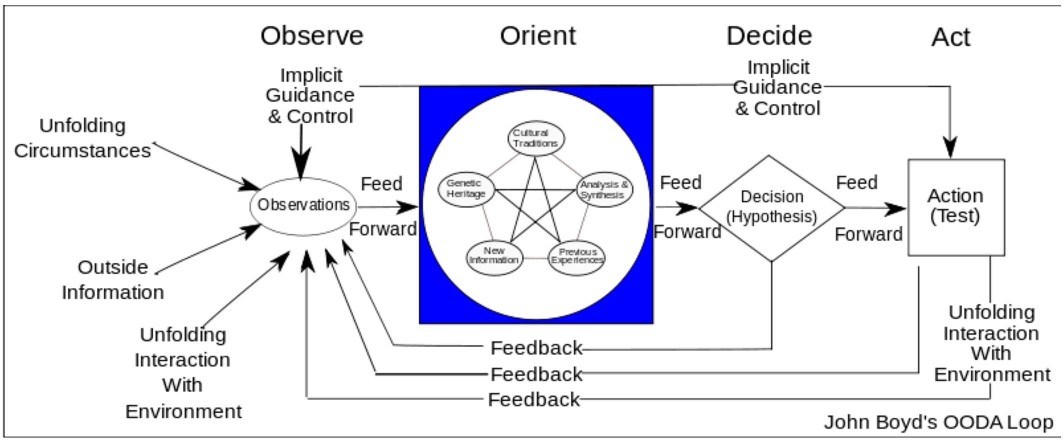


Figure 3. The OODA loop by John Boyd (Source of picture: Wikipedia).

The OODA loop as depicted in Figure 3 illustrates that human decision making and behaviour are influenced by the observation of the external unfolding situation (observe) and the interpretation of the information by the individual (orient). Observe includes visual and aural information gathering and orient comprise the interpretation and categorization of this information. According to Boyd, orientation is the most important phase since it determines the way individuals observe information, decide and behave based on the cultural traditions, previous experience, and genetic heritage. Next, the individual makes a selection of different alternative to come to a decision (decide). The last step is the application of this decision (act). The reaction of this behaviour in the environment is send back to the first phase, orient, and the loop starts again from the beginning. Also, during orientation and decision making feedback of the outcome of these phases is provided to the first phase, observe. As this, the phases in the OODA loop dynamically interact with the environment and the loop repeats continuously. Comprehending the factors affecting the processes in OODA loop of other team members enables them to understand their decisions and behaviours. This loop still is an important principle, or starting point, when designing new complex interfaces and determining how the new tool / technology is used by humans.

4.1.7 Pilots as information managers

Military pilots are rapidly becoming information managers, while piloting their aircraft is almost becoming a "secondary" task. This phenomenon, shift from tactical to planning as described in the trends in Chapter 3, can be seen in other domains as well. This can be illustrated for the fourth and fifth generation of fighter aircraft and by modern airliners.

The F-16 – developed 40 years ago as a single-pilot multi-role fighter – was originally equipped with a cockpit with two small (4") monochrome multi-function displays (see Figure 4). These displays were primarily used for tactical use (radar, weapons, navigation, etc.). Flying the aircraft was made as easy as possible; the fly-by-wire system made that the pilot could concentrate on his/her warfighting tasks. The F-16 was later upgraded with colour multi-function displays that allowed presenting more and more diverse tactical information in an intuitive way (by color-coding the information) and later a monochrome helmet mounted cueing system that presents tactical information directly in the relevant domain: the outside world. A big step forward in operating the aircraft was the introduction of the Link-16 tactical datalink that allows exchanging information between aircraft, strongly enhancing the situation awareness of pilots participating in the mission as well as providing a shared mental picture. Over the years, the use of the tactical datalink has increased significantly. Accordingly, a still growing amount of information is brought to the cockpit and presented head-down and/or head-up and the pilots have to rely more and more on their information management skills in order to make the best of the mission.

Figure 4. F-16 cockpit (source: Wikipedia).

The F-35 was developed from the start as a “flying sensor platform”: it integrates more diverse and more advanced sensors than the F-16. It was also designed from the start to be operated in the context of several datalinks. This is reflected in the cockpit that has two large reconfigurable multi-function touchscreens that present the information from multiple sources in a comprehensive way (see Figure 5). Information is fused as well, to assist the pilot in his/her tasks and to keep task load within reasonable limits. The advanced helmet mounted display allows the pilot to see a clear picture of the environment irrespective of the time-of-day or weather (sensor imagery, both infrared and electro-optical). Even more than in the F-16, the primary task of the F-35 pilot is to maintain situation awareness using the on-board and off-board (datalinked) sensors in order to stay ahead of the developing situation.

Figure 5. Artist impression of the F-35 cockpit with two large multi-function displays that appear as one display area. The monochrome HMD imagery is illustrated with the green "blob" (source: bestfighter4canada.blogspot.com).

The glass cockpit in civil aviation originates from the 1980s (see below in Section 4.1.5). The Airbus family of aircraft can be taken as an example. While originally the cockpit consisted of six colour displays accompanied by several dedicated instruments and controls, the latest cockpits integrate more information on the larger displays while the number of dedicated instruments and controls has decreased (see Figure 6). Functions that are not flight critical are presented on dedicated displays for each pilot, comparable to Electronic Flight Bags (EFBs) that are used on other aircraft. These additional displays replace much of the paperwork that pilots used to bring to the cockpit. At the same time, several new sources of information were integrated in the cockpit on the displays and in the audio cues: Traffic Collision Avoidance System (TCAS), Enhanced Ground Proximity Warning System (EGPWS), weather radar, Automatic Dependent Surveillance – Broadcast (ADS-B), etc. Just like in military aircraft, flying is made as easy as possible by fly-by-wire technology so the crew can concentrate on efficiently processing the information ("managing the flight").

Figure 6. The Airbus A340-600 cockpit (top) that was designed in the 1980s, versus the latest Airbus A350 cockpit (bottom) that was designed over the last few years. (sources: Airbus.com)

Whereas the current generation of glass cockpits is quite advanced, it is still primarily developed around the "one function per display" paradigm (e.g. flight parameters on the primary flight display, engine information on the engine display, the flight management system has its own user interface). Since the type of information needed varies over the flight (flight phase) and depends on the external situation (weather, traffic, terrain, etc) and the state of the aircraft (e.g malfunctions), it may be more optimal to group information in a different way than traditionally and to integrate the EFB-like non-critical information. This approach is taken in Thales' ODICIS cockpit concept (see Figure 7). This cockpit is also utilizing direct interaction principles on the primary display area. For example, the flight plan can be directly altered on the primary display area instead of on a dedicated flight management system interface; the related approach charts are displayed on the same display; the crew thus has all information and controls related to a task (navigation in this case) in the same area in the cockpit. Note that although the ODICIS concept looks futuristic, it is aimed for the 2020 timeframe[1].

[1] Note that for these types of developments business jets are often leading. Possibly they are already operational in business jets.

Figure 7. Thales ODICIS cockpit concept. Source: Aviation Today (source: ODICIS: Aviation Today).

4.1.8 Working position

From an operational perspective multiple situations exists in which team members in the tower would prefer to switch their working position to improve visibility and line of sight. For example, the runway controller needs a good view on the take-off and landing runway, while the ground controller needs a wide-ranging overview on the gates and taxiways. Switching working position is often impossible since interfaces at one position are pre-configured to a specific function. In addition to technological restriction, there are some human factors concerns related to switching working position. Many coordination activities and visual scan patterns of team members in the tower are highly automated behaviours that do require little mental resources. For example, the flow of inbound and outbound flight strips, or the direction a runway controller has to turn to see runway 18C. If team members regularly change positions the predictability of other's behaviours, and evidently their physical position, would decrease with possibly negative impact on controllers' workload and attention management. While the impact of flexible working position would be the highest in the familiarization phase, some inefficiency may remain later on. Inefficiency could arise due to less predictability of other team members' position in the tower, or less routine of a visual scan patterns associated with a specific position.

An illustrative example of the effectiveness of team members' expectations can be found in basketball, namely the 'blind pass'. The player with the ball passes the ball to the receiver without seeing the actual position of this team member. This is only possible if the team members have a highly shared understanding of the situation and each other's position (Salas, et al, 2007). Although this example is not directly comparable to ATC, it indicates that without exact knowledge about other team members complex cognitive resources are required.

In other dynamic but procedural driven working domains fixed working positions are typically more common than flexible working positions. For example, in the civil cockpit the captain usually sits on the left seat while the first officer sits on the right seat. The main reason for this fixed working position lies in advantageous regarding flying the aircraft (e.g. line of sight during landing), but it also contributes to more standardisation in the cockpit.

Finally, note that the preference for fixed positions in the tower are primarily influenced by physical interaction with the outside world (e.g. look out of the window) and with team members (e.g. pass a paper strip). It is totally conceivable, that with new technical means such as electronic flight strips and reconfigurable consoles, a 'predictable' seating position is less important.

4.1.9 Teamwork

Co-ordination between team-members in a team of ATCOs is central in achieving a safe, orderly and expeditious flow of traffic. In 2008, Eurocontrol published a Team Coordination Study providing more understanding of teamwork as well as a baseline from which to consider new staffing concepts for Air Traffic Control ATC**Invalid source specified.**. Besides understanding team co-ordination at a behavioural level, it is important to be aware of the level of underlying cognitive processes, of which, according to Klein (Klein, 2000), the most important are:

- Control of attention
- Shared situation awareness
- Shared mental models
- Application of strategies and heuristics to make decisions, solve problems, and plan
- Metacognition (thinking about other team members' thinking)

ANSPs have basically three instruments in successfully staffing their ATC units:

- Selecting the appropriate teams,
- Designing the appropriate ATC tasks to be performed by these teams, and
- Providing the appropriate competency-based training to perform those tasks.

In the transition to a new staffing concept, essential competencies of the team need to be preserved and new competencies may be required.

The competencies required for teamwork are under normal operating conditions are mostly task specific, however some task-generic competencies are required under non-normal operating conditions.
In tower operations (as in ATC centres) fellow team-members change frequently (from shift to shift). This requires team-generic competencies.
Teamwork in the tower is different from that in e.g. en-route control. In the tower several different roles are distinguished with potentially more hierarchical issues. Also several of these functions can be combined for example in night conditions and de-combined in peak times. Assistants can relieve the controllers of some of the workload, requiring them to provide a second pair of eyes and a pro-active attitude.
Important factors influencing teamwork and team performance when considering staffing concepts are:

- automation support,
- system degradation,
- team workload,
- attitude of team-members towards teamwork,
- working style, and
- team culture.

4.2 External influencing factors

4.2.1 SESAR

"Europe will see a doubling in demand for air transport by 2020 according to projections. The new SESAR technology will allow ANSPs to better communicate coordinate and share information among themselves and with aircraft, as well as more accurate information on the position and trajectory of the aircraft. Consequently, ANSPs will deliver a better quality of service at a lower unit cost for airspace users." http://www.sesarju.eu/players/information

SESAR will lean on predictable time tables not just flight plans but also 4D trajectory planning is a key. As a result arrival and departure times at airports will be predicated better and more accurate. Therefore less deviation from planning will occur and less improvisation from controllers will be needed to maintain a high efficiency / capacity.

4.2.2 4D trajectory planning

As part of SESAR, 4D trajectory management is considered a key improvement of air traffic operations, in particular to increase the overall predictability of traffic, with benefit to airlines and air traffic management. Reference business trajectories (RBT) will be agreed between the airspace users and the service provider. Besides the route (in 3D) the time that flights cross certajn waypoint are predetermined (4D), with a certain tolerance window.

As a first step towards time based operations, to facilitate more a flight efficient approach phase, several Airports/Air traffic control centres focus on Arrival Management with a controlled time over (CTO) the initial approach fix. Examples are LVNL's Speed and Route Advisor (SARA) and the EU project Environmentally Responsible Air Traffic (ERAT) involving the Swedish ANSP LFV and their approaches on Stockholm Arlanda (Bos & Muynck, 2010).

A higher predictability in the flight phase with requirements down to plus or minus 30 seconds over the initial approach fix will increase the demands for punctuality and efficiency on the airport surface.

4.2.3 Airport collaborative decision making

Airport operations rely on the collaboration of multiple parties that perform a series of sequential and parallel processes (Zon et al, 2012). Especially the involvement of multiple parties makes it difficult to cope with disruptions swiftly. Airport Collaborative Decision Making aims at synchronising these processes. Four levels are distinguished **Invalid source specified.**:

- Level 1 aims at information sharing and uses a milestones approach to the turn-around process
- Level 2 aims at improving punctuality by applying collaborative management of flight updates and calculation of variable taxi times.
- Level 3 is to enhance flexibility and recover from disruptions, by collaboratively defining a departure sequence and deal with adverse conditions
- Level 4, the advances level, shares information with more parties (e.g. pilots and apron personal) using new technologies such as datalink and GPS.

Currently the ATC tower receives a departure planning from CFMU and waits for the call for a start-up for each flight. When an aircraft is delayed in its process to off block time, ATC is often not or very late notified. An A-CDM process will provide more up to date information and a more reliable planning to the ATC tower.

In order to make this process work collaboration between the different (main) stakeholder, CFMU, Airline, Ground handlers, Airport and Tower (Zon et al, 2012) needs to intensify. Technological , communication related and cultural challenges need to be solved. These challenges will in the future, and are now already, affecting the work at the tower, and are requiring more intense information exchange with other stakeholders from the tower staff.

4.3 Systems and automation

4.3.1 Goal of automation

The goal of automation as defined by the European aviation community is improving aviation safety and efficiency, and specifically contributing to achieve and fulfil the key performance areas of SESAR (increase safety, reduce environmental footprint, reduce costs). Although many systems operate on a high level of automation, full automation is not the goal by its own, but the goal is to support the achievement of the performance objectives (Brunet, de Boer, Gollnick, Loth, Martinez, & Nieuwenhuisen, 2012). For example, systems should predict and mitigate technical and operational issues, including weather, before they arise (European Commission, 2011). When primary tasks are automated reliability is of high importance since even systems which are extremely reliable yet imperfect negatively affect controllers' attention and performance (Rovira & Parasuraman, 2010). In the following paragraphs various developments in automation are described and evaluated against the overall goal of automation as described above.

4.3.2 Integration of systems

The Integrated Tower Working Position (ITWP) is a research project carried out by Eurocontrol to integrate multiple airport air side system components into an integrated position in the tower (http://www.eurocontrol.int/eec/public/standard_page/proj_ITWP.html). The goal was to improve common information management for tower controllers. For example, an entity (e.g. aircraft) is not represented on various displays in various formats, but integrated in on interface. In the published report about the HMI Solution Specification the interface requirements for an ITWP are discussed, including specific human factors principles, alert management and display management (Eurocontrol, 2009). This and other reports of the project provide thorough guidelines for integration of systems in the tower.

4.3.3 Universal working environment

In the modern cockpit much of the information is displayed on electronic displays. These displays provide a uniform display / interaction mechanism, but they are flexible in terms of content. In the modern military cockpit information on displays, be it head-down, head-up or helmet-mounted, is largely configurable. The displayed information is dependent on the situation or mission phase. Pilots can also rapidly configure settings (of sensors, processing, and displayed information) by selecting a so-called 'master mode' (e.g. air-to-air or air-to-ground).

4.3.4 User interface integration and diversification

Two (opposite) developments can be observed in civil flight deck designs. The first development is ongoing integration of information on electronic displays. The user interface for the pilot has evolved from a large amount of electro-mechanical instruments to a "full glass" cockpit consisting of several large electronic displays. Modern standby instruments are also electronic, so very few dedicated electro-mechanical instruments can be found on a modern cockpit such as that of the recent Boeing 787 (see Figure 8).

Figure 8. Recent Boeing 787 cockpit with a large display area and virtually no separate indicators. (Source: airliners.net.)

The diverse trend started with the introduction of EFBs. EFBs were originally intended to replace the large amount of paperwork that pilots carry with them while on-board (weight saving advantage). In later stages the EFBs were also coupled to the existing avionics and other, non-critical functions were added such as electronic checklists and moving taxi-maps. More recently, low-cost tablet computers such as Apple's iPad were introduced on the cockpit as well (see Figure 9). They take a similar function as the EFB, but are more easily upgradeable in terms of software (both the operating system and the apps) and hardware (a new generation is introduced on the market yearly, maintaining software compatibility). Pilots are also familiar with these very user-friendly devices in their private time. Cabin crew are also equipped with tablets or smartphones to improve (personalize) the service level for the passengers.

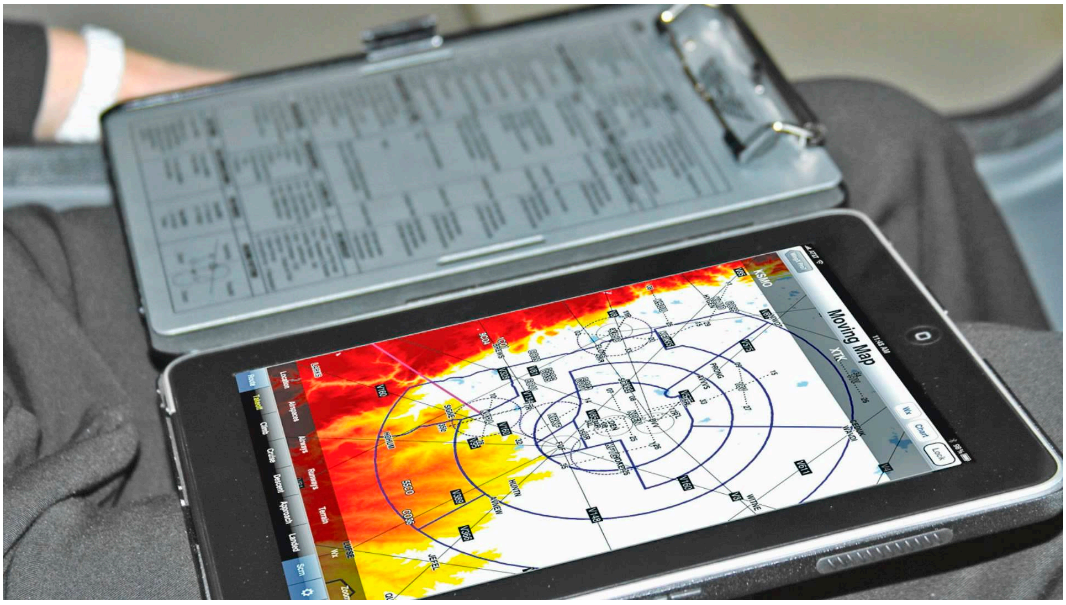


Figure 9. American Airlines EFB solution based on Apple iPad (source: youtube).

A very similar trend can be observed in the military world. For example, NLR recently completed a study regarding improving teamwork in and between transport and attack helicopters (e.g. Roos & Reus, 2013). An information exchange concept was developed and tested based on a consumer-oriented tablet (see Figure 10). The tablet app allowed monitoring mission progress, sharing points-of-interest via the map, creating and sharing sketches and watching live video feeds. The end-users (pilots, loadmasters, ground forces) were particularly enthusiastic about the user-friendliness of the concept; this in contrast to most dedicated military equipment they are used to.

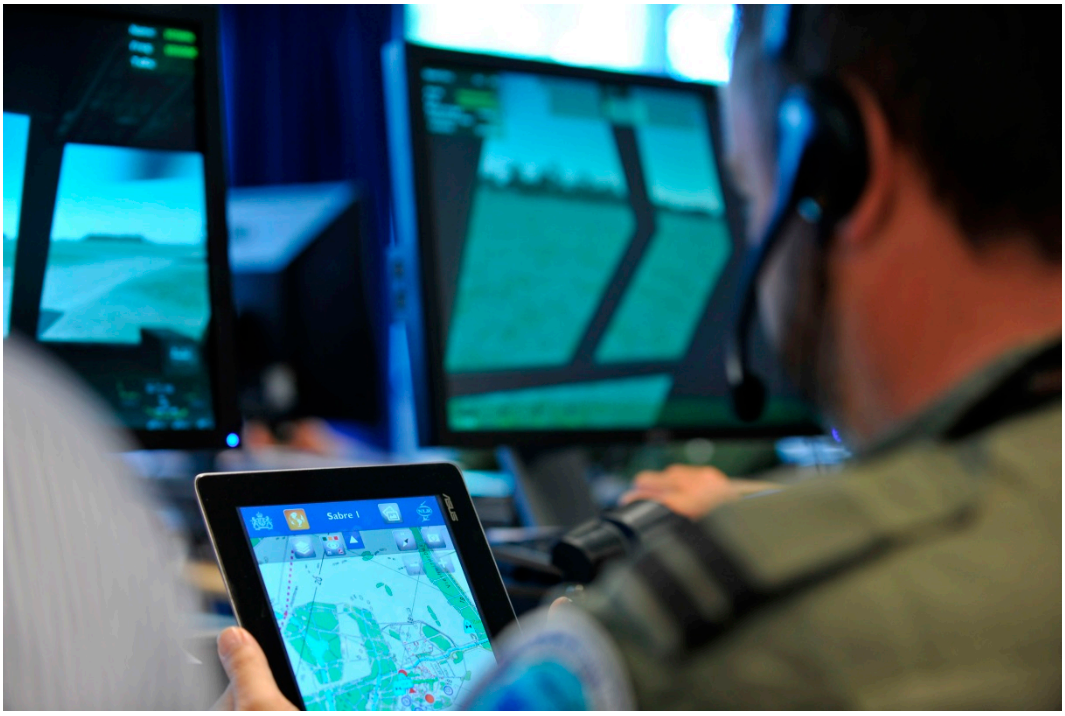


Figure 10. Tablet-based information exchange concept as developed by NLR during an evaluation session.

4.3.5 Personalised intelligent agent

On an iPhone, the user can literally ask Siri to answer questions, to make recommendations and to perform actions. A key feature of Siri is that it can delegate subtasks to other services, either on the iPhone itself or on the web. Google Now, available on Android, works on the same principle, however, it can also passively provide information to the user in anticipation of the users' information needs, and based on their search habits, location, type of connection, etcetera. These two examples from mobile technology make clear that an intelligent agent is not a replicate of a human team member by definition. It is rather an additional 'brain' or information source that can be consulted or actively provides information. This type of intelligent assistants could be particularly helpful in an air traffic control tower, for example if multiple parties need to coordinate their actions and exchange significant amounts of information as it is the case in CDM.

4.3.6 Alerts and advisory systems prioritised and integrated

There are several systems in civil aviation that aim to inform the pilots of imminent threats such as collisions with other traffic or terrain and system failures with consequences for flight safety. Flight crew alerting systems have been applied very successfully in civil aviation. Critical factors are:

- The systems are intended as safety net. The systems are not generating a constant stream of alerts that could ultimately lead the flight crew to ignore them. In other words: when the system generates an alert, the crew knows that they should give it their full attention.
- The alerting system is highly integrated. A single processor collects status information from multiple subsystems and presents the overall status and the alerting itself in a uniform way.
- Some alerting systems are not integrated, but in that case the visual and auditory signals are designed in order not to conflict with other alerting systems.
- The systems use both visual and auditory signals, both as attention getters and as indications for the mitigating actions.
- Alerts are prioritised according to the severity of the situation. Warnings that require immediate action have priority over cautions that require immediate attention but no immediate action. These in turn have priority over advisory that require awareness (and maybe an action) and informational messages that require no action. The attention getters are for these categories are clearly distinguishable.
- The systems are accompanied by situation displays. This helps the crew to anticipate future events and helps to provide the context of an alert.

Alerting systems are part of the airworthiness certification (e.g. EASA CS-25.1322, 2013), and their overall design is standardised over manufacturers because of SAE Aerospace Recommended Practice ARP4102/10 Rev. A, 2007.

4.3.1 Big data and data mining

Humans are not very good at finding interesting information in large datasets, unless supported by automation. Processing the so called big data, or data mining, is the subfield of computer science that is automatically (or semi-automatically) discovering patterns in large datasets. The overall goal of the data mining process is to extract information from a data set and transform it into an understandable structure for further use. It may be used for machine learning or predictive analysis **Invalid source specified.**.

With increasing amounts of data being stored the predictability of time required for different activities on the airfield may increase distinguishing between for example aircraft types, airlines and weather conditions.

Such information may further increase the punctuality of a planning, may be integrated in a decision support system or considered in an airport Collaborative Decision Making process.

4.3.2 Performance-based operations

Performance-based operations include exact navigation in the three dimensions (lateral, vertical, longitudinal) while including time as the fourth dimension. This results in 4D-trajectories which enables aircraft to fly more efficiently with regard to environmental aspects, safety and noise. The 4D-trajectory is provided by the ANSP and executed by the cockpit crew. The aircraft ideally travels along this route and only deviates from the route for separation purposes or other safety related needs. Performance-based operation is a key element of SESAR and NextGen and requires a common effort from airliners, airports and ANSPs. From an ANSP perspective the biggest challenge is to reach optimal gate tot gate planning. A crucial development in that is an Arrival Management (AMAN) system, which facilitate optimal planning.

4.4 Future systems

4.4.1 Automated take-off, landing, recovery and avoidance systems

Commercial aircraft are equipped with automatic landing systems, and UAVs are able to carry out automatic take-offs and landings. Automatic landings are part of daily operations, as 98% of European airlines land on autopilot. However, there is potential for increased use of automation, particularly in the case of an emergency. Recovery and avoidance systems, as well as automatic fully automated landings could be helpful and safe life in case of crew incapacitation or disorientation. The integration of digital information in the aircraft systems, supported with high levels of automation will make it possible to develop prognostic safety systems that can prevent accidents or can perform automated recovery in the case of emergencies. Although these technological developments are not directly related to ATCOs, they indirectly affect their work. Automated take-offs and landings are highly predictable and enable a controller to give clearance far in advance. This could be an effective workload management strategy to prepare peak hours.

4.4.2 CPDLC – “Controller Pilot Data Link Communications”

Controller Pilot Data Link Communications (CPDLC) comprises that air traffic controllers send digital instructions and clearances, rather than communicating via voice. CPDLC messages then appear in a cockpit display system and are confirmed by the pilot. CPDLC can also interact directly with an aircraft’s flight management computer, contributing to process automation while improving accuracy. The development of CPDL communication resulted from the foreseen increase in air traffic that will lead to congested frequencies and unmanageable amounts of R/T.

CPDLC is assumed to decrease controller and pilot workload and reduce potential errors. Research has shown that the advantages of CPDLC are primarily significant in high workload situations when there is little time for verbal communication. During time periods with little traffic, human factors aspects such as situation awareness, workload, attention, and frequency of information exchange, are comparable between CPDLC and voice communication (Stedmon et al, 2007). In addition, non-nominal situations require often exchanging specific information that is not easily transferred by CPDLC. In such situation, voice communication will probably always be preferable to digital information. The situations in which CPDLD is most efficient are characterised by quite a lot of traffic without any deviations from normal operations.

4.4.3 ADS-B – "Automatic Dependent Surveillance-Broadcast"

As in all sections in this Chapter the information provided below is not the vision for the tower itself, it is a development that is spotted in the world and that might affect the tower in a direct or indirect way. This development was one of the sources of inspiration, a building block, for the vision provided in Chapter 2 and some of the trends in Chapter 3. In that context the development is useful to be aware of, when considering the technological future of the tower. However, just like for all the other developments in this chapter, it is not stated that this is a fact that will happen exactly as described here.
This document provides a vision, inspired upon more than developments that can be observed in the tower right now. It is not a plan, guideline, or target, just a vision.

ADS-B uses a combination of transmitters and receivers to provide flight crews, ground control personnel and air traffic control with, amongst others, information about the position and speed of aircraft. ADS-B might replace a layer of radar surveillance by using information derived on and transmitted by aircraft (ADS-B OUT) although it is not expected to replace a primary radar. The on-board ADS-B transmitter uses information from a Global Navigation Satellite System (GNSS) receiver, which derives precise position and velocity of the aircraft from the GNSS constellation. It transmits that position and velocity together with, amongst others, the aircraft's altitude, vertical rate and aircraft identity.
ADS-B provides the possibility to make various aircraft parameters available to ATC besides position that can be obtained from radar and multilateration. Amongst these are parameters that could be of relevance to airport controllers like selected departure runway and SID and ground routing. Moreover, ADS-B allows aircraft parameters that are of interest to tower controllers but not yet part of the current ADS-B message set to be added in the future. This will take some years but makes the technology more interesting.

Several benefits are associated with ADS-B for both ATC and airlines. For example, ADS-B offers the opportunity to provide both tower staff and pilots with the same information, as such it could increases aviation safety by enhancing shared situation awareness of air traffic controllers and pilots through real-time information of aircraft position information. As such, operational staff is not only aware of other traffic in a specific area but also has a shared understanding since they have access to the same information.

4.4.4 Advanced-Surface Movement, Guidance, and Control System (A-SMGCS)

The concept of Advanced-Surface Movement, Guidance, and Control System (A-SMGCS) is aiming at increasing the efficiency and safety of ground operations. The levels 1 and 2 which are currently being implemented, assist the air traffic controller providing Situation Awareness on the position of aircraft and other vehicles on the airport (level 1) and by automatically monitoring for runway incursions based on radar data (level 2) (Eurocontrol). Levels 3 and 4 provide guidance to pilots and vehicle drivers by means of on-board moving maps. It will provide situation awareness on the location of other traffic (level 3) and this functionality together with CPDLC as enabling technology, allow the presentation of the taxi route to the flight crew provided by the ground controller (level 4). The flight crew (and air traffic controller) will be warned when deviating from the cleared route or in the worst case when entering the secured area around a runway.
Level 3 and 4 by providing more situation awareness to the flight crews and drivers on the airport surface will further minimise the need for the controller to monitor the traffic.

4.4.5 Remote tower

Roessingh et al (2009) found: “Remote control of airports implies application of cameras to replace direct visual observation from airport control towers by projection of the airport and its traffic in a remote control canter. Remote airport control is an emerging technique with mainly benefits for smaller airports because it reduces the cost of personnel.”

Even though the remote tower is initially developed for smaller airports, aspects of the design may in the longer run be relevant for LVNL towers and therefore a number of the findings and characteristics of the Advanced Remote Tower (ART) project too. On the one hand for smaller towers under the control of LVNL like Rotterdam, Lelystad, Beek, etc. On the other hand, within the remote tower projects there was research aimed at merging information from different sources in order to increase Situation Awareness and to reduce the head down time. The principles of this research could also be helpful when redesigning the so called “tower centrum” at Schiphol.

Roessingh et al, 2009 listed that the particular ATM problems that the Advanced Remote Tower (ART) project attempts to solve are the following:

1. Automatically correlating the approach radar picture with the camera picture as to provide continuous and automatic tracking of targets.
2. Improving the situation awareness of ATCOs through automatic labelling of targets in the projected 360 degrees outside view.
3. Improving the projected outside view through image processing in order to increase the fidelity of the projection (in terms of similarity with the outside view from the actual tower).
4. Increasing the visibility of the outside visual view through image processing as to lower the minimum RVR (‘visibility threshold’) at which LVPs would come into effect, which in turn enables the continued operation under normal visibility procedures.
5. Further enhancing situational awareness by presenting weather/wind information in the outside visual view, thereby decreasing the need for the ATCO to attend to separate weather displays.

During the SESAR Innovation Days 2013 it seemed that progress was made within this research. LFV and SAAB presented collaboratively the progress that was made on this project. It was clear that they still aim for the smaller airports. However, technological developments that are made may, in combination with other developments, be relevant to bear in mind for LVNL at Amsterdam Airport Schiphol (AAS) as well. Examples are: cameras that track aircraft automatically and merge the data from optical cameras with infrared and radar; solutions to weather, birds and insects that may disrupt proper and continuous functioning of the cameras; Software tools to emphasise relevant items and changes to a situation; software tools that continuously compare the image that the camera records with previous images, and as such, quickly spots the smallest items on or near the runway that should not be there; warning systems that bring these changes under the attention of the ATCO; tools to make perception of depth and distance more realistic; and adjusted procedures to make sure that operation with these new tools is still safe.

There is truly a great deal of research going on around this topic. Given the fact that Schiphol foresees to expand further, also with respect to buildings that may hinder the view from the tower, lessons learned from this project may be provide solutions to that situation.

4.4.6 Augmented reality

Augmented Reality (AR) is a live or copy (e.g. via a camera) view of a physical, real-world environment whose elements are augmented by computer-generated sensory input (definition: Wikipedia). The technology functions by enhancing one’s current perception of reality.

Augmentation is conventionally in real-time and in semantic context with environmental elements.

With augmented reality technology, artificial information about the environment and its objects can be overlaid on the real world. In order to achieve world-conformal augmenting cues, an augmented reality application needs to be precisely aware of the position of the user and the viewing direction.

Two main advantages can be identified. Firstly, there is less need for the human operator to combine information from different sources. For example, in an air traffic context, AR technology could overlay semantic information such as aircraft labels, the status of a runway, stop bars, etc. on the real world. Secondly, the user can keep looking outside and has less need to refer to head-down displays.

Several examples of AR technology exist outside air traffic control. A recent example of AR technology is Google Glass (Figure 11). This is a wearable see-through display with touch and voice input capabilities. Devices such as Google Glass allow the user to keep looking “head-up” and to obtain the required information there, instead of looking “head-down” on a display. Note that the transparent display of Google Glass is not centred in front of the eye, so the user still has to shift eye gaze to read the display.

Figure 11. Google Glass, a wearable display providing functions similar to augmented reality (source: youtube.com).

World conformal symbology is being displayed on most military helmet mounted displays, both for tactical purposes (e.g. a symbol indicating where a target is) as well as for flying the aircraft or helicopter (e.g. for landing, see Figure 12). Although this is seldom called AR, it has all the characteristics of it.

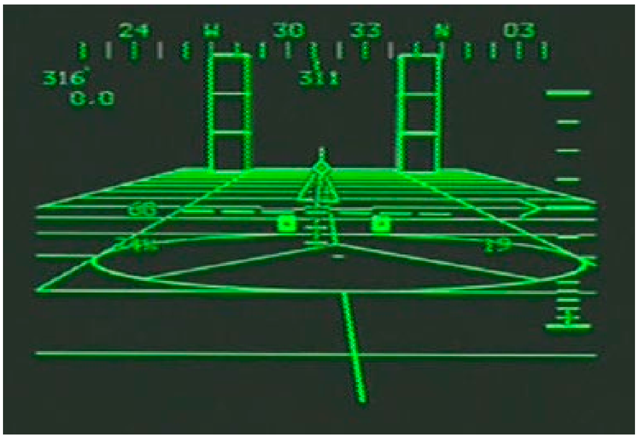


Figure 12. World conformal HMD symbology (to be superimposed on the outside world, the black parts are transparent) aimed to help helicopter pilots to land in low visibility conditions (source: Ferranti Technologies).

Augmented reality is also being investigated for in-car applications and for pedestrians with a smartphone (see Figure 13 and Figure 14). Assuming a more or less fixed position of the car driver, it is possible to display world conformal cues on the windscreen. Obviously, these can then only be seen when looking forward. In the case of the smartphone, sensors allow measuring position and orientation of the device. The augmenting cues can then be overlaid on the device's camera imagery.

Figure 13. Augment reality concept from BMW showing world-conformal cues for obstacle avoidance (source: bmwblog.com).

Figure 14. Nokia City Lens overlays information from a digital map on a smartphone's live camera imagery, helping to find your way around cities for example (source: nokia.com).

Combining information from different sensors and presenting that in an AR kind of way, will also take place at the tower. Google glasses like tools or projections on the window in the tower, will support operational staff at tower by providing a more effective information presentation.

4.4.7 Input by Swype

Swype is a means to put data into a computer. It is designed for touch screens like on smartphones or tablets. On the screen a keyboard is displayed. The operator moves with a stylus or finger over the touchscreen, thereby also moving over a number of keys. The software determines the word that the operator, most likely, wants to enter. It displays the word and the operator can accept or adjust / reject (see Figure 15).

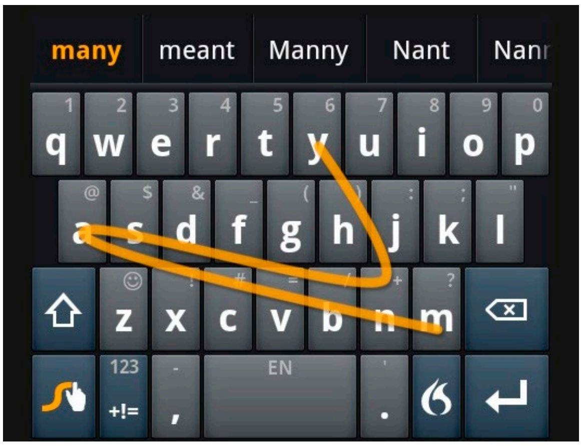


Figure 15. Swyping the word 'many' (source: letsgodigital.org).

The same principle can be used for games. A player can for example swipe over a map to indicate a route that his character has to travel. The player indicates approximately what he wants the character to do, and the game-software translates it to detailed instructions for the character.

Such a system could also be beneficial for the future tower, for example to enter taxi routes. By using this simple and non-time consuming way to enter a route it does not require a lot of effort or attention from the ATCO. When it is entered and accepted it can be send to the aircraft and processed. Or it can be send to the system that switches on the “greens” on the taxiways. After this the ATCO can monitor the aircraft’s progress but does not need to actively engage any more. As long as the ATCO can provide this input in advance, it will increase his capacity to provide instructions to the aircraft.

For the ways of operation in the tower this can be described as an example of a means to provide higher level instructions than the ATCO normally does, and leaving the details of execution of these instructions to the automation.

This touches on a more general principle, and that is user intent recognition. Swype functions by combining a context (in general a language, and often preceding words Swyped) with the user input. The automation in this case selects the most likely user intent. This relies on the user checking the input, and on a fall-back mechanism in case the intent is not correctly recognised.

4.4.8 Electronic flight strips other forms of information presentation

Electronic flight strips intend to replace the paper strips used in air traffic control towers in the future. Electronic flight strips integrate different pieces of information, including system information and manual input information of the controller. This information is immediately available to all controllers and working positions in the tower and therefore enhances shared situation awareness. Information is displayed in a customised manner, providing specific pieces of information needed at specific working position. Other information can be displayed on demand but is not per default shown to every controller. Thus, electronic flight strip enable presenting information just in time, just with the right content, and just the right amount of information. In order to reach this aim, the main goal of flight strips, namely aiding cognitive processing, and the specific needs of the various roles in the tower should be taken into account (Durson et al, 2008). For example, start-up/delivery controllers use strips for making manual notes to manage workload and support communication; runway controllers make notes on flight strip as mnemonic, to organise information, and to support their mental picture; ground controllers write notes on flight strip for similar reasons as both start-up / delivery and runway controllers. In the design of electronic flight strips these needs should be integrated.

Electronic flight strips should not merely mimic paper flight strips but should add additional value. Therefore it is important to take the functionality of paper flight strips into account and not simply translate or digitalise the current working methods. In addition, electronic flight strips increase safety and efficiency by enhancing cognitive processing. For example, although the term ‘electronic flight strip’ implicates that information is stored on a ‘strip’ other concepts are possible. In the future an interactive radar screen could display the aircraft on an airport and flight information could become visible by merely clicking on the aircraft. While such a concept would require different working method than today, it could support controllers’ mental work by presenting flight information in an integrated way and according to spatial orientation instead of sequential orientation.

5 Golden rules

The golden rules are those issues that should be considered when implementing any new development in the tower. New development refers, in this context, to new technologies, but also new procedures, new team composition, or even accepting new tasks from stakeholders outside the tower. In fact the rules stem from the text in the previous Chapters, they are a list of issues that should be considered, but also more practical rules of thumb, that should be applied. Note that some of these golden rules are already (partly) applied at LVNL. Having a rule listed below does not mean it is not part of the current way of implementing new technology, but indicates it is an issue that should be taken care of. Some issues written down will therefore be part of existing practice, some will be additional to this way of working. The rules are grouped according to the trend that they are connected to.

General

- Keep preparing for the arrival of new technology: New technology will always appear.
- Cater for the needs of a new generation of air traffic controllers, but adapt the pace of changes to take the current generation into account.
- The concept of visual momentum (Woods, 1984) is an important issue in the modernization of the control tower. This concept should be applied to the linking of information between different displays and between displays and the – possibly supported by virtual reality – augmented world.
- Modern approaches to interface design (EID, Bennet, 2011), Vicente (1999), and system design (CSE and resilient systems (Hollnagel, 2008) can help shape the design process of systems and interfaces.
- Using concepts on information presentation (Tufte, 1983, 1990 and 1997) the improved quality of visual displays can be fully exploited. This also solves issues with visual momentum, by having more global images emerge from a display with more subdued detail.

Operational role

- Maintain an up-to-date description of the responsibilities and tasks of the tower personnel.
- Use possible future scenarios to estimate changes in responsibilities and tasks.
- Use the current and future (both technological and operational) situation to build a future-proof human-machine interface

Working position

- The geometry of the consoles, the human-machine interface hardware and the information presentation style should be uniform.
- Each role can select an optimised ‘view’ on the data. This view can partly be customized to the desires of the person representing that role.
- For each role, there is a minimum information requirement that is always shown.
- The working position might contain multiple input methods, so that operational staff member can choose.
- The working position contains multiple input methods.

- Temperature, illumination and volume of the sounds/alerts/warnings can be set individually for each position.
- One’s settings should not hinder other staff members.

- COTS equipment shall be integrated in tower based on business case analyses (taken into account criteria such as costs/benefits, flexibility, etc.

- Information exchange between privately owned and company equipment must : conform to the non-functional requirements of the system (like performance, availability, accuracy, security, etc.)

- Critical elements in the human-machine interface should remain standardised.

Information integration

- A thorough task analysis is recommended to determine what (combined) information is compulsory or nice-to-have for each role.
- Information priorities must be set per role and are the basis for an integrated HMI and alerting mechanism.

- The HMI must still be functional when information sources are in a degraded state. The HMI must never present misleading information. For example by creating a main, back up and last resort system.

- Digital information sharing between stakeholders must be supported as good as reasonably possible.
- Information about reliability, authorship, redundancy, validity etc. of all kinds of information items is needed to combine and mine data.
- Only authorized personnel or systems can add, modify or delete data.

Consistent human machine interface

- A human machine interface design philosophy must be defined, for example by taking one of the flight deck design philosophies as examples.

- The design philosophy should be used as the single standard for in-house developments and to provide a basic set of requirements to equipment suppliers.

Support for human sensors

- Sensor technology could enhance the human's perception of the outside world. This is especially so where it concerns situations that are difficult to monitor with bare eyes watching through the tower windows.. Its data should be integrated with other systems.

Automation

- Automation should free up cognitive resources for maintaining SA and tactical decision making.
- Automation should guide the operational staff member's attention towards items or situations most relevant for him/her.

- An automation philosophy for the control tower needs to be defined, in relation to or as part of the human machine interface design philosophy.

- Automation is based on a thorough task analysis and is applied for low-risk, low-uncertainty rule-based tasks.

- The level of automation is inversely related to the risk association with the task.

Intelligent agents

- Intelligent agents could be applied for tasks that the machine is better at.
- The work share between agent and human operator must be unambiguously clear.
- The human operator must be able (a) to trace the reasoning of an intelligent agent's advice or action and (b) to overrule the agent.

Planned operation

- Human machine interfaces should (also) present information related to the future state when that supports the specific role of an operational staff member. However, safety-critical current information always has priority.
- Consider the use of the data mining technology to recognise patterns and use this to feed intelligent agents and to plan operations.
- For some tasks, decision support tools should be considered (tools that can quickly present the effects of certain (planning) decisions, before execution of the plan).
- The representation of information and HMI should be adjusted to how strategic or planned the operation is.

Teams

- Maintain an overview of the different kinds of teams that can be identified (within the tower or with team members outside, and fixed or flexible teams) and use their different requirements.
- Consider the use of proven team communication means such as chat, video conferencing and even, less proven, social media. (Compare with a nowadays way of information exchange between ATCOs via strips.)

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Appendix A Workshop

A workshop was organised on 18 November 2013 at the LVNL premises. The aim of this workshop was to gather operational input and reactions to the idea's that were formulated so far, and that were meant to be used as input for the vision. The procedure for the workshop was to confront the participants with statements and ask them to respond either as themselves or as representatives of certain roles. Besides the organisers 12 persons (ranging from researchers to operational tower staff) participated. In this Appendix the slides that were used for the workshop as well as the final outcome are included.

Eventually the workshop answered the following questions:

1. What is the **most realistic innovation** that you have heard today?
2. Name **one** (possible) **innovation that was not discussed today**:
3. What **should definitely be part** of the human factors vision for future tower technology?

The most frequently given answers were:

Most realistic innovation	Not discussed today	Needs to be included in vision
Personal Intelligent Agent and CDM	Digital strips (or even more elaborated)	Will visual ATC remain or not
Personal Intelligent Agent	Digital strips	First establish the problem then act
Remote TWR for smaller airfields	Technology to support cognitive processes	Human and technology both have their specialisation
Personal Intelligent Agent	Digital strips en head up displays	What is human's and what is machine's responsibility
CDM computer	Digital strips	Quiet and well-arranged working stations
Personal Intelligent Agent and CDM+	Digital strips	The human should be central in the vision
Data sharing	Use camera images as system input	Human should always understand what technology is doing
Information selection and clever algorithms	Digitise communication (for example data link)	Human and technology both have their specialisation
Small scale Personal Intelligent Agent	Digital strips (share information between working positions)	Focus more on human than technology
Personal Intelligent Agent+	Digital strips	Human operator is more important than technology
Integrated information	Is augmented information presentation feasible and realistic	Accept higher LoA's though human should be in control
Easy to process information available at the right location	Voice communication (probably not just radio)	Is different support for different working stations needed?

vision for future tower technology

workshop november 18, 2013

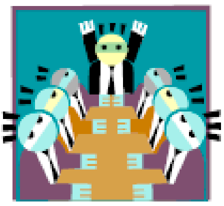
agenda

12:00	welcome and aim of meeting – mariska
12:05	workshop set up and personal introductions
12:15	crossfire
13:15	the sky is the limit
15:15	wrap up
16:00	end

crossfire

a pleading game

left side of the room is "team left"



right side of the room is "team right"

each team pleads sometimes against and sometime pro

crossfire

a pleading game

- ten provocative positions
- one at the time
- per team 1 minute to select an appropriate spokesperson
- we'll indicate who pleads "pro" or "anti"
- each spokesperson has exactly one minute
- then two minutes of interaction between teams

in the future ...

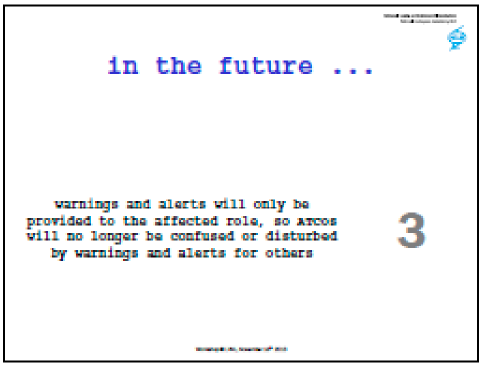
the system has become so easy and intuitive to operate that less trained staff can do the job

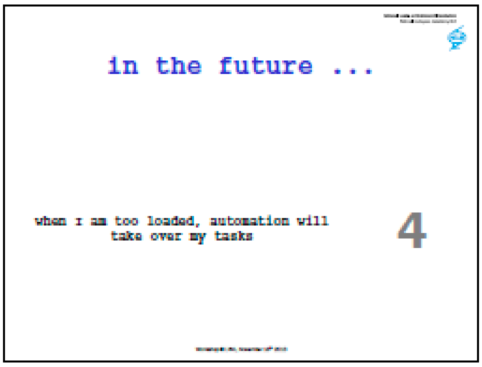
1

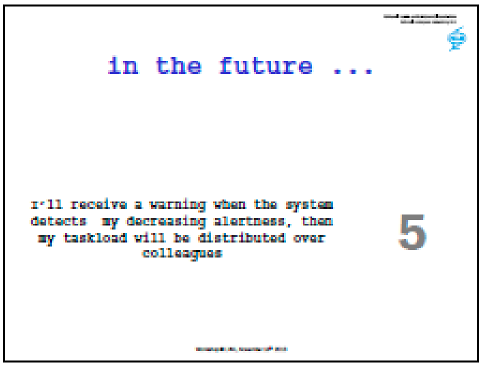
in the future ...

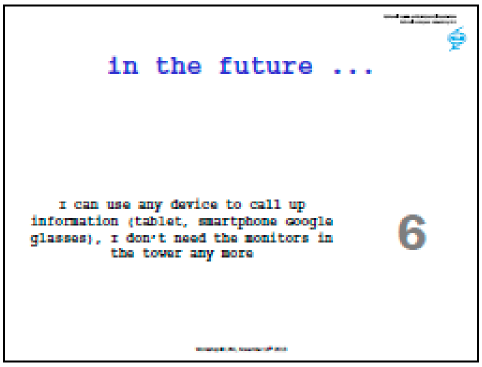
I can, better than nowadays, manage my workload by strategically performing tasks in advance, or postponing them

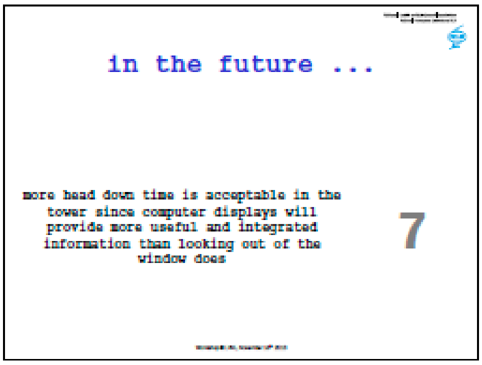
2

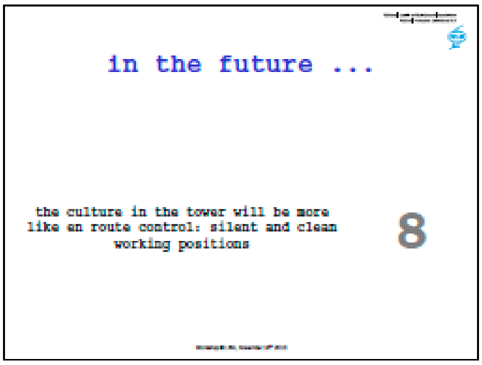

in the future ...
warnings and alerts will only be provided to the affected role, so ATCOs will no longer be confused or disturbed by warnings and alerts for others
3


in the future ...
when I am too loaded, automation will take over my tasks
4


in the future ...
I'll receive a warning when the system detects my decreasing alertness, then my taskload will be distributed over colleagues
5


in the future ...
I can use any device to call up information (tablet, smartphone google glasses), I don't need the monitors in the tower any more
6


in the future ...
more head down time is acceptable in the tower since computer displays will provide more useful and integrated information than looking out of the window does
7


in the future ...
the culture in the tower will be more like en route control: silent and clean working positions
8

in the future ...

automation will be able to run the majority of the ATC processes, only in case of major disruptions (airport closure, extreme weather, etc.) ATCOs will interfere, therefore assistants will become superfluous

9

in the future ...

the remote tower will be displaying a perspective on the airport depending on the active runway configuration

10

the sky is no limit

a look into the future

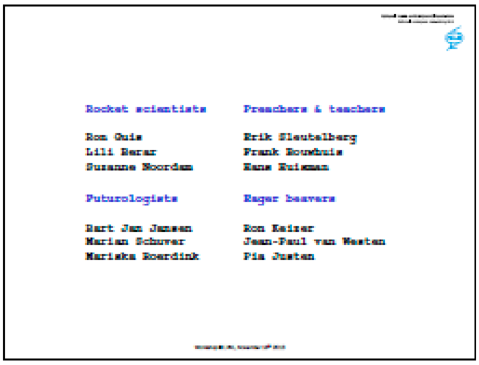
we are going to the year

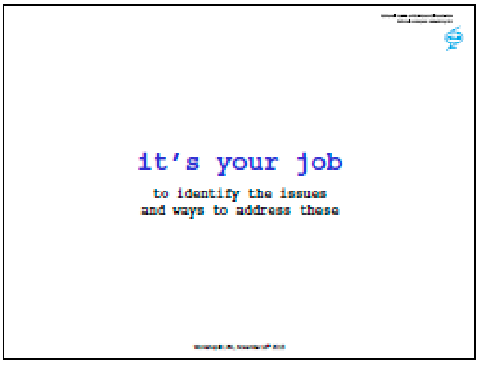
2050

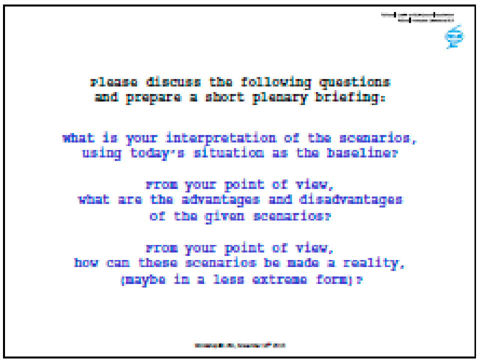
however, we are now in

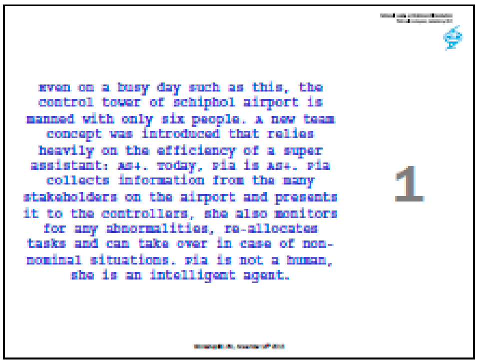
2013

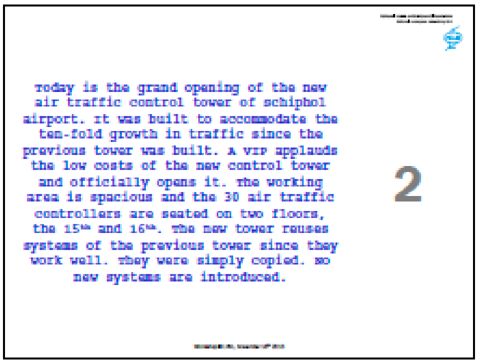

congratulations
you are part of the team
to make the future happen

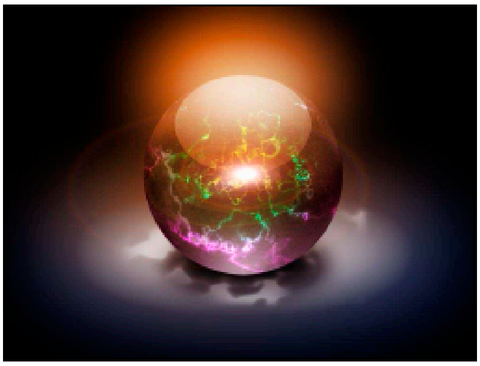

Rocket scientists
Ron Quis
Lili Berar
Suzanne Noordam
Futurologists
Bart Jan Jansen
Marian Schuver
Marieke Roerdink
Preachers & teachers
Erik Sleutelberg
Frank Bouwhuis
Hans Huisman
Eager beavers
Ron Keizer
Jean-Paul van Westen
Pia Justen

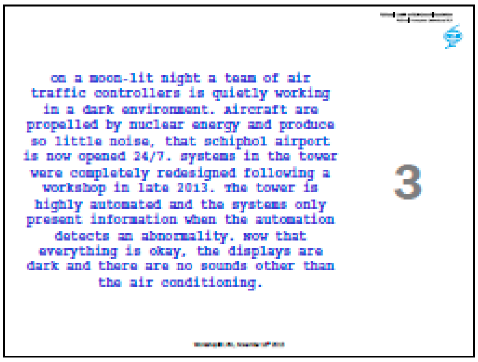

it's your job
to identify the issues
and ways to address these

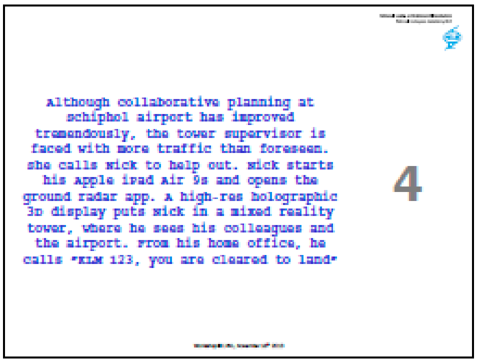

please discuss the following questions
and prepare a short plenary briefing:
what is your interpretation of the scenarios,
using today's situation as the baseline?
from your point of view,
what are the advantages and disadvantages
of the given scenarios?
from your point of view,
how can these scenarios be made a reality,
(maybe in a less extreme form)?


Even on a busy day such as this, the control tower of Schiphol airport is manned with only six people. A new team concept was introduced that relies heavily on the efficiency of a super assistant: AS+. Today, Fia is AS+. Fia collects information from the many stakeholders on the airport and presents it to the controllers, she also monitors for any abnormalities, re-allocates tasks and can take over in case of non-nominal situations. Fia is not a human, she is an intelligent agent.
1


Today is the grand opening of the new air traffic control tower of Schiphol airport. It was built to accommodate the ten-fold growth in traffic since the previous tower was built. A VIP applauds the low costs of the new control tower and officially opens it. The working area is spacious and the 30 air traffic controllers are seated on two floors, the 15th and 16th. The new tower reuses systems of the previous tower since they work well. They were simply copied. No new systems are introduced.
2




On a moon-lit night a team of air traffic controllers is quietly working in a dark environment. Aircraft are propelled by nuclear energy and produce so little noise, that Schiphol airport is now opened 24/7. Systems in the tower were completely redesigned following a workshop in late 2013. The tower is highly automated and the systems only present information when the automation detects an abnormality. Now that everything is okay, the displays are dark and there are no sounds other than the air conditioning.
3


Although collaborative planning at Schiphol airport has improved tremendously, the tower supervisor is faced with more traffic than foreseen. She calls Nick to help out. Nick starts his Apple iPad Air 9s and opens the ground radar app. A high-res holographic 3D display puts Nick in a mixed reality tower, where he sees his colleagues and the airport. From his home office, he calls "KLM 123, you are cleared to land"
4


KEEP
CALM
AND
WRAP IT
UP

WHAT IS NLR?

The NLR is a Dutch organisation that identifies, develops and applies high-tech knowledge in the aerospace sector. The NLR's activities are socially relevant, market-orientated, and conducted not-for-profit. In this, the NLR serves to bolster the government's innovative capabilities, while also promoting the innovative and competitive capacities of its partner companies.

The NLR, renowned for its leading expertise, professional approach and independent consultancy, is staffed by client-orientated personnel who are not only highly skilled and educated, but also continuously strive to develop and improve their competencies. The NLR moreover possesses an impressive array of high quality research facilities.

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