

Zero Failure Management at Maximum Productivity in Safety Critical Control Room

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Abstract—Predicted growth in air traffic and demand for increased safety, predictability, and efficiency impose additional demands on Air Traffic Management (ATM) systems. Different technologies are currently under development to address these demands. However, one area continues to leave significant room for improvement: productivity in the control room. This paper proposes improvement of control room productivity by applying productivity improvement methods and techniques and validating them in the context of a tower control room. We describe our approach, the challenges it poses, and our plans for validation. We believe that this approach could be useful for improving different ATM processes and could provide useful input for the development of automated tools used in control rooms.

Keywords—component; Air traffic management, Tower control room, Productivity improvement

I. INTRODUCTION

There is an increasing demand for improving Air Traffic Management (ATM) systems, in general, and in Europe, in particular. Over the past decade, approximately nine million passenger flights and 700 million passengers used European airspace every year. The European Commission has recently published a white paper on the "Roadmap to a Single European Transport Area" [1], which stresses the importance of transport and mobility to the economy and highlights several other areas. The SESAR® program, a combination of the Air Navigation Service provider (ANSP) and industrial effort, is vital for the development of robust and future-oriented solutions. In addition, several research initiatives have been taken, and numerous technologies have been developed over the past years. The results of such inquiries have been presented to the ATM community through ATC Global and EUROCONTROL's Innovative Research Workshop, among others.

However, one area continues to leave significant room for improvement: productivity in the control room itself. Different approaches to process improvement have been proven successful in mass production industries, such as the automotive industry, and are now increasingly used in other domains.

In order to improve the productivity and safety of the highly-automated ATM control room, we therefore propose a four-step productivity process called the Zero Failure Management at Maximum Productivity in Safety Critical Control Room process (ZeFMaP), which incorporates permanent improvement cycles.

The four steps of ZeFMaP include the following:

- Modelling the target process into a production workflow and dividing it into "production steps."
- Optimizing the "human machine symbiosis" for each step (outside the scope of our research).
- Analyses of the decision points and decision content within each of the steps with the aim of offline optimization for each decision of the overall process and the improvement of each production step through a feedback loop.
- Improvement of the target process through a feedback loop.

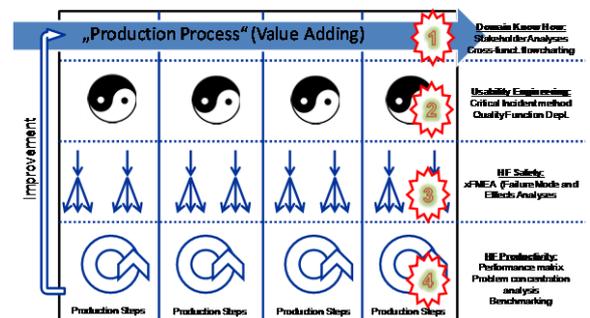


Figure 1. ZeFMaP Process

The ZeFMaP process is a four-step improvement process that will apply best practices from productivity improvement in mass production industries and adapt it to meet the challenges of ATM.

Our hypothesis is that the implementation of such a method should permanently improve the quality of the processes in the control room by optimising productivity and minimising false decision failures. In this project, we will test this hypothesis

within the context of a tower (TWR) control room. Applying production improvement theories from domains other than the ATM domain is, however, far from being a straightforward technology transfer; it poses several challenges. First, we must identify the advantages and disadvantages of existing improvement approaches used in the ATM context. Second, we must model the control tower processes in a way that makes them suitable for the application of productivity improvement methods and techniques. Third, we must develop and validate a productivity improvement approach tailored to the needs of the tower control room. Finally, our hypothesis will be tested while the technology in question (a highly-automated tower control room) is still under development; as such, this will require the development of novel concepts and evaluation methods.

The remainder of the paper is organized as follows. Section II describes state of the art productivity improvement, and Section III describes the case of this project (control tower process). Section IV presents the ZeFMaP approach, and Section V describes the expected outcome of our project.

II. PRODUCTIVITY IMPROVEMENT

Throughout most industrial history, process improvement has been a topic in industry and academic literature. In literature, this topic dates back, at least, to Shewhart's work on statistical approaches to process improvement. Since then, different industries and different academic fields have developed a number of different approaches for improving processes. In no particular sequence, we will present some of the main overall approaches:

Improvement based on process modelling holds the key assumption that industrial processes are usually complex chains of activities [2]. By visualizing illogical process steps, lack of responsibilities, poor process integration, etc., graphically modelling the process largely contributes to process improvement [3]. A number of different modelling techniques have been developed, ranging from higher-level modelling of stakeholders and requirements of a process, simple mapping of process steps, and assigning organizational ownership of steps in the models, to more complex models, including capacity and load information [4], [5]. For all of these, computer tools of varying complexity have also been developed, and companies' modelling processes can choose from a wide range of commercially available software. Examples of applications can be found in almost any type of industry, with published case studies from extremes, such as automotive and health care [6], [7].

Improvement based on the application of improvement tools, especially in the field of quality management, has developed a wide range of improvement tools (see, for example, [8], [9], [10], and [11]). These can be applied at different stages of an improvement effort and can often trigger creativity and push improvement efforts when the process has become stagnant

[12]. The main strength of this approach lies in the capacity of such tools for revealing patterns and connections and for forcing the organization to view the process from many different angles [13]. By organizing the various tools in a structured improvement process (typically consisting of phases, such as process mapping, analysis of shortcomings, creation of ideas, evaluation of solutions, etc.), this approach also helps facilitate the improvement process by prescribing the overall steps to follow. Like modelling-based improvement, this approach is highly generic and is applied in every imaginable type of sector – from schools to charities and from services to mass production.

Improvement based on problem solving is similar to the tool-based approach, but exploits a problem or lacking performance as a specific starting point for the effort. While a more generic improvement effort can have “looser” ambitions of improvement (e.g., customer service), this approach starts from a defined shortcoming of a process: for example, frequent breakdowns of a machine or stock shortages of a certain product. Many of the same tools are used as in the tool-based improvement approach, but are structured in a different manner as part of an overall problem-solving process [14], [15]. A key focus of this approach is an emphasis on identifying and eliminating the so-called root cause(s) of a problem (as opposed to mere symptoms or intermediate causes) [16], [17]. As a generic approach, problem solving is widely applied in many different industries and sectors.

Improvement based on waste reduction is a collective term for methods that were first developed as part of the Toyota Production System approach [18], [19], later refined in the more general Just-in-Time methodology [20], [21], [22], and, finally, included in the latest “generation” of this approach: lean [23], [24]. While employing other tools and techniques, these (originally an automotive sector approach) focus on waste reduction, zero defects, and other ambitious goals through the use of methods like value stream mapping, fool proofing, etc. While waste reduction and optimum utilization of available resources is perceived as a key focus (as implied by the term “lean”), there are several other facets to these approaches. Over the years, their adoption has gradually expanded from a very specific initiation in the automotive industry (Toyota, in particular), to other manufacturing industries and, later, to service sectors and the public sector.

Improvement based on performance measurement is, to some extent, a variant of improvement based on modelling and improvement tools, but with emphasis on the active use of quantitative and qualitative measurements of performance. Measurements are often analysed using statistical tools and are compared with external references through benchmarking. This approach is singular in its reliance on measured performance data about process drivers and outcomes [25] but also insofar as measurement is exploited as a means of influencing employees' behaviour (what is measured is prioritized) [26] and linking processes and their focus to enterprise strategy (one key aspect of balanced scorecard methodology [27]). Like many of the other approaches, performance measurement was originally

developed in the manufacturing industries [28], but is today prevalent in all sectors.

Improvement based on automation eliminates human effort from a process by exploiting various means; for “physical” processes, automation is achieved by using robots, conveyor belts, automated equipment, etc. [29], while for intellectual processes, the route to automation goes mainly through ICT solutions [30]. Automation is often combined with one or more of the other approaches: for example, a process is first streamlined by applying lean principles [31] before automating the remaining operations. With an ever-widening chasm between labour costs in industrial countries compared with those of emerging ones, automation has become one of the pillars of retaining both manufacturing and service industries in Western countries.

Improvement based on employee participation and involvement is not an equally specific approach, as those mentioned above, but still represents a unique philosophy of improvement. The underlying rationale is that employees inside a process, who are in continuous contact with the customers of and suppliers to the process, know best what must be improved [32]. Since they must also obviously be part of the solution and accept it, any improvement effort should rely heavily upon them. This is achieved through various means of involvement and empowerment. Some examples include organizing processes with so-called process owners and process teams [30], conducting improvements through teams of employees (either from the same organizational unit or cross-functional teams [33]), and creating self-guided process teams that democratically plan, execute, and monitor their work. While some specific approaches under this heading fit better in a manufacturing context, the underlying principles of employee involvement are universal and applicable to any type of organization.

A rather recent approach, “Integrated Operations” was originally developed in the oil and gas industry as a means of facilitating closer cooperation between different disciplines, team-based work processes, use of virtual collaboration, and more automated production processes. The overall objective is to achieve enhanced productivity and safety by moving planning and decision making from offshore to onshore and by strengthening the support from the onshore organization utilizing expert centres and suppliers. Integrated Operations rely on state-of-the-art ICT, extended use of real time data, shared screens, and virtual collaboration through extended use of video conferencing. The concept of Integrated Operations is currently going through “generations” [34]: Generation 1 mainly concerns the enhanced collaboration between onshore and offshore, wherein leadership teams have become one integrated team across distance through the establishment of operation centres, both onshore and offshore, and the extended use of video conferencing. Allocation of activities from offshore to onshore has been another important part of Generation 1. Generation 2 is mostly concerned with onshore collaboration, with the establishment of expert centres, and virtual collaboration, with suppliers. The new work modes of

Integrated Operations have been implemented using a combination of the previously mentioned improvement techniques that are “packaged” in such a way that deserves mention as a concept of its own. Some challenges experienced with the implementation of Integrated Operations have included collaborative decision-making and virtual collaboration, with special attention to trust and leadership [35], [36]. The integrated leadership team represents an increased and common situational awareness. This enables the team to make good decisions in critical situations and decreases the probability for major accidents. Some of the approaches to Integrated Operation are spreading to industries that face similar challenges (e.g., land-based process industry).

Another type of improvement is that based on innovation and the development of new technology, new processes, and new products. This is not a well-defined improvement approach, as much of the industrial improvement being achieved stems from, more or less, systematic activities that are aimed at innovating technology, products, and processes. At the heart of such activities are methods for facilitating the two, often irreconcilable, concepts of creativity, on the one hand, and structured development, on the other. As a result, this “school” blend formalized, so-called, stage-gate processes [36] with creativity-enhancing techniques. Stage-gate processes dictate that any development project must meet certain criteria at pre-defined milestones or stage-gates, and the project is typically subjected to an external review that determines whether this is the case. The more ambitious the innovation efforts, the more marked the funnel shape of the process; a large number of ideas are started, but these are screened and winnowed down so that only a limited few make it through to commercialization. The challenge is often to combine such a rigid structure with the need for creativity and the ability to pursue many different concepts. To some extent, innovation is present in every type of sector, but with vast differences in innovation rate.

From this brief overview, it should be clear that a large number of improvement “philosophies” exist – philosophies that, to some extent, are intrinsically different in their main choice of enabler of improvement (e.g., problem-solving vs. automation vs. employee involvement), but which also overlap, and often rely, on some of the same or similar tools and techniques. Some of these have been developed by/for specific industries, and others are generic. As they are quite different in nature, we also believe that there are differences in how well suited they are for application in an air traffic setting. In Section IV, we will assess the suitability of the different approaches for the aviation industry.

III. CONTROL TOWER TASK MODELLING

One of the first steps in a process improvement effort is to identify the processes involved; the next step will, in many cases, be to model them in a workflow. This is done in order to gain a better understanding of both the details and the overall purpose of the processes. Workflows and processes in ATM centres have certain characteristics that need to be considered when modelling. This section will address these characteristics,

elaborate on the potential challenges these pose to successful modelling of these processes, and use examples from a current control tower to illustrate.

Successful process improvement relies and builds upon a set of "building blocks". In other words, process improvement must be prepared for, and the organization needs to be motivated, educated, and aligned in order to fully utilize the potential provided by the methodology.

A. Characteristics of Air Traffic Management Centres from the perspective of process improvement

Traditionally, the improvement effort is based on user participation and involvement (ref Section II). The aviation industry is characterized by a high degree of standardization and use of guidelines. Even if local adjustment exists, all towers and control centres need to be well coordinated, as changes made in one place will affect others. The control towers and centres are handling a large amount of aircraft movements, and top concentration is needed for most of the working day. These conditions put some restrictions on the participation and involvement approach.

B. Initial modelling of control tower workflow

The first step in our effort to develop a productivity-driven method is to provide an initial model of the workflow in a control centre. Our work will be case-oriented, and the ZeFMaP project has decided to use the TWR processes at Hamburg Airport as our main case. The case will include the processes and activities from an approaching aircraft that is under control of the tower controller via taxiing the gate to the departing aircraft when leaving the control of the tower controller.

First, we produced a Hierarchical Task Analysis of the processes at Hamburg Airport TWR. Based on this, we created a process-flow chart that contains all steps of the ATC related part of an airport. Figure 2 provides an excerpt of this flow chart, which illustrates only a small portion of the total control tower workflow involved in our case.

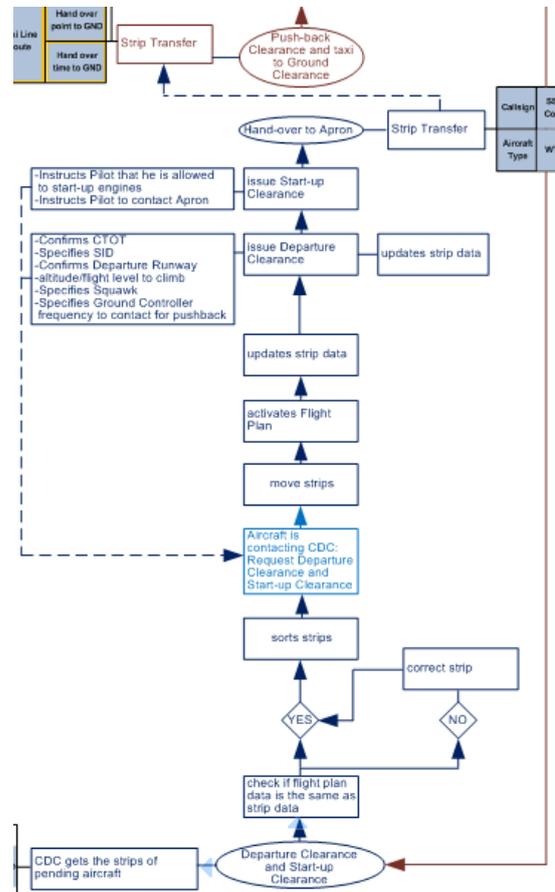


Figure 2 Excerpt of the process-flow chart

An important element in the flow chart is to illustrate the information exchanged between the different controllers and actors/roles involved in our case. This is illustrated using "flight strips," indications of information flows, and points of coordination (as illustrated in Figure 3).

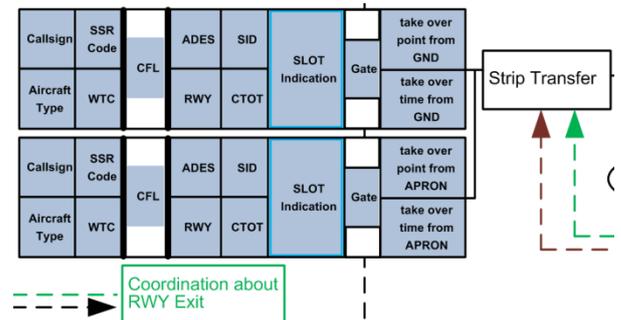


Figure 3 Provided information to the controller

One part of our approach will be to analyse each decision point in order to illustrate what basis is used to make decisions and where to find that information. For each decision point, we have extracted what the decision is based on and what help could be provided for each decision (as illustrated in Figure 4).

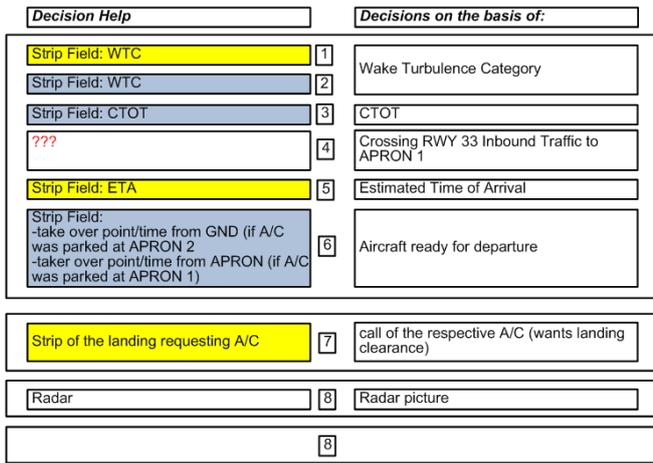


Figure 4 Decision point analysis

C. *The development of process workflow maps and identification of improvement areas*

Throughout the course of the ZeFMaP research project, we will transform the work flow chart, information flow, and decision point analysis into a process workflow map using "swim lanes" to illustrate the different tasks and responsibilities of each involved role or actor and the connections and interdependencies between them. This method allows us to illustrate the different information systems being used to coordinate actors and share information. The final process map will then be used to identify improvement areas and initiate process improvement efforts on a more detailed level that involves representatives from each actor/role.

D. *The productivity-driven method*

This will result in an initial description of the productivity-driven method. In order to construct this method, we will rely on the different methods and techniques introduced in Section II. The applicability of these methods and techniques in aviation is discussed in Section IV, and we will base the development of the productivity-driven method on the methods and techniques deemed most suitable for use in our case. Guidelines for the future improvement effort will be developed and described based on good practice from different industries.

IV. ZEFMAP APPROACH

Our objective is to improve the productivity and safety of the tower control room by implementing a four-step productivity-driven method that incorporates permanent improvement cycles. Through an iterative process we will develop and validate a set of productivity improvement methods and tools.

A. *Productivity Improvement*

In this paper, we have provided an overview of many different improvement approaches that are applied in different industries. The ZeFMaP project will develop and test an improvement approach that has been adapted to the challenges

faced by the aviation industry. As the context is quite different from many other industries, adaption is required. In most industries, individual companies run their own improvement processes to the extent that improvements are widely adopted throughout an industry; this is due to benchmarking, dissemination of knowledge, copying, etc. In the air traffic management setting, many best practice processes are "centrally" developed and rigorously tested before they are rolled out for implementation across the sector or in regions. There are, of course, exceptions to this rule; large corporations in various industries also develop new processes that are imposed on local units, while air traffic control centrals can undertake local improvement projects. Still, the inherent differences create some difficulties that make it impossible to simply copy methods from other sectors and apply them to aviation.

In Table I, we have conducted a simple analysis of key characteristics of each approach and whether they might prove useful for the improvement of ATC control rooms.

As this table demonstrates, most improvement approaches possess features that are positive in relation to being applied in the aviation industry; however, there are also issues that might present challenges. In fact, this exercise is hardly able to sufficiently conclude which of the approaches are more or less suitable for adaptation to an ATC control room context. On the other hand, the exercise has clarified those approaches that are available, and the next logical step is to collect empirical data about usefulness in aviation.

TABLE I. RELEVANCE OF IMPROVEMENT APPROACHES

Improvement Approach	Characteristic Features	Relevance for ATC control rooms	Expected Benefits of Application in ATC control rooms	Perceived Challenges of Application in ATC control rooms
Process modeling	<ul style="list-style-type: none"> Gaining deep insight into the logic of the process Collective understanding of the process among process participants is important Use of visualization tools 	<ul style="list-style-type: none"> Also aviation contains large number of processes that can be modeled Many aviation processes already well documented and described by detailed procedures An assumption that many stakeholder and inter-personal process relationships have not been mapped 	<ul style="list-style-type: none"> Clarify process relationships that go beyond the information and communication technology (ICT) system sphere Focus on involvement and collective understanding can aid empowerment and local initiative in an ATC control room Visual process models provide input to ICT system development 	<ul style="list-style-type: none"> Application of involvement-based approach requires withdrawing people from operative service Individual air traffic controllers can view their work as a series of individual tasks, barrier against seeing more comprehensive chains of tasks as processes
Improvement tools	<ul style="list-style-type: none"> Structured process for process improvement Large improvement toolbox available Toolbox contains both qualitative and quantitative, analytical and creative tools Large portion of tools designed for application in groups of people 	<ul style="list-style-type: none"> The toolbox is generic and should be applicable in aviation Some of the challenges faced by the aviation industry lend themselves to certain tools 	<ul style="list-style-type: none"> Provide structured method for addressing challenges faced Application of tools can break down barriers between actors in the industry Many tools proven to contribute to significant improvements 	<ul style="list-style-type: none"> Application of involvement-based approach requires withdrawing people from operative service Effective use of tools require training and experience Improvement work requires inner drive in the organization and people that function as change drivers
Problem solving	<ul style="list-style-type: none"> Main focus on solving specific problems Relies on use of many of the same tools as the tool-based improvement approach 	<ul style="list-style-type: none"> The toolbox is generic and should be applicable in aviation Some of the challenges faced by the aviation industry lend themselves to certain tools 	<ul style="list-style-type: none"> In cases where specific problems/challenges can be identified, targeted problem-solving is a "gratifying" activity based on organizational demand 	<ul style="list-style-type: none"> Application of involvement-based approach requires withdrawing people from operative service Effective use of tools require training and experience
Lean/waste reduction	<ul style="list-style-type: none"> Focus on leanness/agility, "pull" as opposed to "push", and minimization of waste Also clear focus on zero defects In addition to strong underlying philosophy, also reliance on various tools and techniques 	<ul style="list-style-type: none"> Important aviation challenge related to resource utilization and waste 	<ul style="list-style-type: none"> Lean thinking strong "fad" with proven results in many sectors 	<ul style="list-style-type: none"> Intrinsic conflict between lean principles and aviation's need for safety-oriented redundancy and slack
Performance measurement	<ul style="list-style-type: none"> Collecting qualitative and quantitative performance data from work processes Using what is measured to influence people's behavior Performance measurement can link strategy to operational tasks 	<ul style="list-style-type: none"> ATM is a sector with much data Air traffic controllers are already used to being measuring various results and processes 	<ul style="list-style-type: none"> Collecting more systematic performance data can feed other improvement processes Performance measurement can be used to reinforce implementation of improvements 	<ul style="list-style-type: none"> Current measurement focus in aviation seems to be on end results (punctuality, capacity utilization, etc.), effective performance measurement dictates measuring more performance drivers
Automation	<ul style="list-style-type: none"> Elimination of manual, human effort Motivated by cost savings, safety, handling of large volume, etc. 	<ul style="list-style-type: none"> ATM deals with large volumes of "transactions" Long tradition of using ICT systems and trusting them 	<ul style="list-style-type: none"> Achieving further volume increases with current or even reduced resources warrants further automation 	<ul style="list-style-type: none"> Remaining processes/tasks not yet automated possibly difficult to automate Implementation of new systems/equipment costly and time consuming
Employee participation and involvement	<ul style="list-style-type: none"> Involvement of employees at all levels to create ownership of improvements and changes Tap into the knowledge and creativity of everyone involved in a process Stimulate an organizational culture of "self-management" 	<ul style="list-style-type: none"> ATM employs many highly educated people who must make decisions continuously 	<ul style="list-style-type: none"> Involvement-based approach can further exploit the knowledge and ideas of all employees Irrespective of how improvements are created, employee involvement can help ease the subsequent implementation process 	<ul style="list-style-type: none"> Impression that ATC control rooms operate under a logic of individual tasks and responsibilities, thus less tradition for such collective efforts
Integrated operations	<ul style="list-style-type: none"> Critical decision making Team based work modes and virtual collaboration Real time data and shared screens 	<ul style="list-style-type: none"> Similar setting with layered organizational structure and "control room" logic Experience from implementation of more team-based work forms Similarities regarding critical 	<ul style="list-style-type: none"> The oil and gas industry has been at the forefront in developing and implementing this new approach Lessons learned could be relevant for ATM 	<ul style="list-style-type: none"> The pace of operations and the volume of transactions are, under normal operations, much lower in the oil and gas industry than in aviation (although drilling operations are more similar)

		decision making <ul style="list-style-type: none"> Oil and gas industry ahead of aviation in restructuring to more centralization/integration 		
Innovation	<ul style="list-style-type: none"> Main focus on achieving improvements through developing new technology, products or processes Utilizes creativity-enhancing methods and tools Often structured through stage-gate processes 	<ul style="list-style-type: none"> ATM is to some extent a technology-driven sector and thus used to innovation 	<ul style="list-style-type: none"> The level of improvements expected to be required in the industry demands innovation in technology and processes 	<ul style="list-style-type: none"> Technology innovation can rarely be achieved by operative employees but often relies on external actors

B. Experimental validation

The overall goal of our validation work is to test whether the ZeFMap process will improve productivity and minimize false decision failures in the TWR control room. More specifically, we will test the following hypothesis:

Application of the ZeFMap process in the TWR control room will significantly improve productivity and safety, measured by the following Key Performance Indicators (KPIs): capacity, efficiency, predictability, safety, and environmental sustainability.

To test our hypothesis, we plan to conduct a family of experiments that compare the productivity of a chosen TWR process that will be measured by the above-described KPIs. Definitions of KPIs can be found in [37]. Those KPIs will be measured with and without the optimization steps of ZeFMaP.

We have chosen Hamburg Airport TWR for our experimental validation because we believe it is of the appropriate size and complexity. Real (past time) traffic data from Hamburg TWR’s control room will be used in our experiments. The experiments will be conducted using the University of Salzburg’s simulator, using its remote simulation functionality. Our testing controllers will participate remotely from their home basis. Researchers from SINTEF and Frequentis will observe the experiments from their offices.

We plan to conduct one experiment that will measure KPIs as they are today and an additional two or three experiments that will measure KPIs of the improved TWP process. The following measures will be used:

- Productivity measures*, such as amount of aircrafts handled per run, taxi time from gate to runway (departures), taxi time from runway to gate (arrivals), taxi distance from gate to runway (departure), taxi distance from runway to gate (arrivals), and coordination between controllers (frequency of coordination, time per hand-off)
- Safety measures*, such as the amount of conflicts and NASA-TLX (Task Load Index) [38]

The experiments will also be used to identify bottleneck in the TWR process. A set of internal measures that captures this will be defined.

In each experiment, we foresee five participants (one for each of the following working positions: Clearance Delivery Controller, Apron Manager, Ground Controller, Runway Controller, Tower Supervisor). The participants will be experienced air traffic controllers. During the experiment, they will conduct realistic tasks that correspond to their roles. To assure this is the case, air traffic controllers from Hamburg Airport will be included in the development of tasks and scenarios that are used in the experiments.

V. EXPECTED OUTCOME

ZeFMaP aims to improve the productivity and safety of the highly-automated ATC control room by implementing a four-step productivity-driven method that incorporates permanent improvement cycles. The experiments will demonstrate how to compare the productivity of the chosen TWR process through the use of KPIs. Those KPIs will be measured both with and without the optimization steps of ZeFMaP. Future work will more precisely describe how KPIs can be connected to the experiments and project outcome.

SESAR project 16.5.2 will assess a trade-off between automated planning and flexible decision-making in ATM by identifying methods for balancing the pre-planning of aircraft trajectories with the need to flexibly respond to unexpected events. The project will intentionally draw on results from 16.5.1 and provide input to 16.6.5 for use in various SESAR operational and technical projects. ZeFMaP provides an opportunity for complementary input and collaboration with 16.5.1 and 16.5.2.

SESAR project 16.5.3 aims to provide the baseline for Human Machine Interface design for the system projects 10.10.2 and 12.5.5. ZeFMaP adds the interworking between these working positions through an optimized process and cross-function learning.

Even in this early stage of ZeFMaP, some effects can be indicated in the following ways:

The first effect is related to the management of flight safety. New knowledge on how "zero failure" might be ensured in ATC control rooms has a wide impact.

The second effect is related to the efficiency of how ATC decisions can be distinguished, to a certain degree, by suitability. Knowledge of this would be of immediate value for ATC training and concept development.

The third and long-term aspect is related to the knowledge of how to develop efficient and permanent improvement processes with the support of future self-learning ATM systems.

ACKNOWLEDGMENT

This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (the SJU) and the EUROPEAN UNION as part of Work Package E in the SESAR Programme. Opinions expressed in this work reflect the authors' views only and EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein. All the authors contributed equally to the paper. The authors want to thank Hamburg Airport Experts for quick responses to all our questions.

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