Development of a Safety Performance Evaluation Process and Supporting Tool for Changes in ATM

Dobroslavić, Tea

University of Zagreb

Faculty of Transport and Traffic Sciences

Tea Dobroslavić

DEVELOPMENT OF A SAFETY PERFORMANCE EVALUATION PROCESS AND SUPPORTING TOOL FOR CHANGES IN ATM

MASTER'S THESIS

Zagreb, 2020.

UNIVERSITY OF ZAGREB
FACULTY OF TRANSPORT AND TRAFFIC SCIENCES
MASTER THESIS COMMITTEE

Zagreb, 6 April 2020

MASTER THESIS ASSIGNMENT No. 5655

Student: **Tea Dobroslavić (0135237375)**
Study: Aeronautics

Title: **Development of a Safety Performance Evaluation Process and Supporting Tool for Changes in ATM**

Description:

Define the aim and the scope of the diploma thesis. Analyse current methods for safety impact assessments of changes in ATM. Analyse current methods for safety criteria determination in ATM. Explain supporting tools of the methods. Consider and analyse other aspects related to changes. Consider potential dependencies and interactions between assessed changes. Define the new Safety Performance Evaluation Process. Give an overview and conclusion of the work.

Mentor:

Associate Professor Biljana Juričić, PhD

Committee Chair:

University of Zagreb

Faculty of Transport and Traffic Sciences

MASTER'S THESIS

DEVELOPMENT OF A SAFETY PERFORMANCE EVALUATION PROCESS AND SUPPORTING TOOL FOR CHANGES IN ATM

RAZVOJ PROCESA VREDNOVANJA SIGURNOSNE UČINKOVITOSTI I POMOĆNOG ALATA ZA PROMJENE U UPRAVLJANJU ZRAČNIM PROMETOM

Mentor: Assoc. Prof. Biljana Juričić, Ph. D.

Student: Tea Dobroslavić, 0135237375

Zagreb, September 2020.

ACKNOWLEDGEMENT

The methods and conclusions presented in this paper are a summary of the results achieved during a traineeship at the EUROCONTROL Experimental Centre. The traineeship was done remotely from April to August of 2020 under the mentorship of Marta Llobet Lopez and with the help of the experts from the DECMA/INO/PM unit, led by Andreas Tautz.

I would like to express my gratitude to my mentor in EUROCONTROL Ms. Marta Llobet Lopez who gave me the golden opportunity to do this wonderful project on the topic of Development of a Safety Performance Evaluation Process and Supporting Tool for Changes in ATM. As well as to the entire Performance & Methods Unit who welcomed me into their team and helped me with my research.

Secondly, I would also like to thank my mentor at the Faculty of Transport and Traffic Sciences Assoc. Prof. Biljana Juričić, Ph. D. who helped me get this opportunity and who believed in me. Thank you to our entire Aeronautics department and our professors for their hard work and efforts throughout the years.

And finally, a big thank you to my family and friends who have supported me unconditionally on this journey. To my family, I want you to know how much I appreciate all of the time and energy you put into helping me throughout my university days. To my friends, thank you for the wonderful memories you all have given me.

SUMMARY

The Safety Performance Evaluation Process is used to estimate the safety impact for a solution or a set of solutions in the frame of SESAR. The Accident Incident Model is used for six accident categories where ATM may make a significant contribution either in causing or preventing accidents. solution impact is assessed for every accident category it can be applied to. For each accident category, the overall risk is calculated by assessing the impact of all the solutions that are affecting the model. When looking at the solution impacts, it can be seen that there are more than one solution impacting the same elements of the same model. Therefore, a relationship impact between those solutions needed to be explored.

KEY WORDS: SPEP, AIM, Safety, Risk, solution, Accident, Relationships

Contents

EXECUTIVE SUMMARY

Risk models, specifically the AIM models in SESAR, are used for setting quantitative safety targets that define what is considered tolerably safe for the change being introduced by a solution or a set of solutions and permit the validation of the expected safety impact of a solution. Trough the SESAR projects, several a conceptual and operational changes are introduced into the ATM system. Before those changes can be introduced into the system, a thorough safety analysis is necessary to be done to assure that those changes will not reduce the overall safety of the system itself.

The Safety Performance Evaluation Process (SPEP) is used to estimate the safety impact for a solution or a set of solutions in the frame of SESAR. The AIM model is used for six accident categories where ATM could make a significant contribution either in causing or preventing accidents: mid-air collision in En-route airspace, mid-air collision in TMA, runway collision, taxiway collision, controlled flight into terrain, wake turbulence accident in final approach. solution's impact is assessed for every accident category it can be applied to. A solution can impact more than one accident category.

For each accident category, the overall risk is calculated by assessing the impact of all the solutions that are affecting the model. That can be calculated by applying the solution benefits at the level of the elements in the model, or at the level of the top events of the model. In this thesis, the focus was on applying solution benefits at the level of elements in the model.

When looking at the solution impacts at the level of elements in the model, it can be seen that there are more than one solution impacting the same elements of the same model. Therefore, a relationship impact between those solutions needed to be explored. Relationships between solutions were previously explored for other KPA. That research was applied to safety in this thesis with the help of SESAR safety experts.

Runway Collision risk model was used in this thesis to explore the impact of traffic growth and relationships between solutions on the overall risk assessment. Runway Collision risk model was chosen for the number of solutions that impact it, as only ten solutions impact it. Traffic increase of 2%, 3% and 4% was applied to the baseline quantification of the model. Later on, the 4% traffic increase was retained for the other exercise because the only difference between the traffic increases applied was the factor by with the impact were multiplied by. Therefore, there was no need to show the results of all those increases, for there cannot be any different conclusions drawn from them.

The 4% traffic increase was applied also when exploring the relationships between solutions. The relationships defined for other KPA were applied to safety, but not all of the predefined relationships could be applied in this particular case. The relationships that were applied to the Runway Collision model were defined as compatible and incompatible. The incompatible relationships were identified for the solutions that were mutually exclusive. For the solutions that are mutually exclusive it is implied that they cannot be deployed at the same time in the same operational environment. Therefore, eight different scenarios were devised keeping in mind that there are no mutually exclusive solutions in the Scenarios.

The compatible relationships were identified as independent and further classified as having cross-effect or no cross-effect. Most relationships were identified as having no cross-effect, meaning that their interactions do not change their safety impacts. Those relationships that were identified as having a cross-effect were quantified using a relationship matrix and expressed through a relationship impact coefficient.

When looking at the overall risk impact of the scenarios, it can be deduced that the relationship impacts were not significant in comparison to the cases were relationship interactions were not applied, or even in comparison to the "do nothing" case. Since the most interactions between solutions were mostly in the same elements of the model, it could not be deduced if the relationship interactions would not have a significant impact in any kind of risk models they were applied to. For that reason, a sensitivity analysis was performed.

The sensitivity analysis was also done for the Runway Collision model, but the solutions used were a generic example that was quantified arbitrarily. Two cases were examined. The first case was applying solution benefit changes only to barriers of the model and, in each iteration, increasing the number of solutions that interact in the same element. The second case was applying changes only to induced events and, in each iteration, increasing the number of solutions that interact in the same element. What can be seen from those cases is that relationships applied at the level of barrier have a higher impact than those applied to the level of induced events.

1. Introduction

This thesis was written as a final step of a traineeship with EUROCONTROL. The title of the traineeship was Development of a Safety Performance Evaluation Process and supporting Tool for changes in Air Traffic Management (ATM). The purpose of the traineeship was to get familiar with the assessments of safety performance for changes in ATM and determining the safety criteria for their development. The task was to formalise the safety performance evaluation process and develop a supporting tool in the frame of Single European Sky ATM Research (SESAR). This process is based on the use of risk models and has to take into account the potential dependencies between Safety and other Key Performance Areas, as well as the interdependencies between the assessed changes.

While examining the Safety Performance Evaluation Process (SPEP) and the risk model on which the process was applied to, a few questions arose. To what degree will the traffic increase have an impact on the overall risk assessment? What kind of impact do relationships between solutions have, and can those relationships even be applied to Safety? At which level and to which elements those relationships need to be applied to?

The purpose of this thesis is answering those questions. It is done so trough eight sections:

1. Introduction
2. Single European Sky ATM Research
3. Safety Performance Evaluation Process
4. Current Methods for Safety Impact Assessment of Changes and Safety Criteria Determination
5. Supporting Tools: Risk Models
6. Potential Dependencies and Interactions Between Assessed Changes for Other KPAs
7. Defining the New Safety Performance Evaluation Process Using the Runway Collision Risk Model
8. Conclusion

Section 2 introduces the concepts of SES and SESAR and the fundamental legislation enabling them. It outlines the terminology and concepts mentioned thru ought the thesis. Its purpose is to help the reader apprehend the rest of the thesis.

Sections 3 and 4 describe the Safety Performance Evaluation Process and its application in SESAR. The four steps of SPEP are explained, as well as Safety Validation Targets and Safety Performance Assessment.

Section 5 explains the concept of risk models and how they are used. It describes different parts of the model and their basic elements. Also, the Accident Incident Model (AIM) is explained in this section.

Section 6 focuses on the dependencies between solutions for other Key Performance Areas (KPAs). It explains relationships that were already defined in other projects. That research is used as a basis later on in the work when exploring relationships between solutions for Safety.

Section 7 shows the results of applying SPEP to the Runway Collision risk model. Safety Impact for each solution is showed. Relationships between solutions are defined and based on them deployment scenarios are created. The overall risk for each scenario is calculated. A sensitivity analysis is performed to consolidate the collected data.

2. Single European Sky ATM Research

By the end of the last century, especially in the late 1990s, air traffic demands were starting to become too much for the outdated and obsolete technology and procedures that were in use at that time. As a response to severe flight delays in Europe in 1999., the European Commission launches The Single European Sky (SES) initiative in 2000 (1).

The Single European Sky ATM Research (SESAR) project was launched in 2004 as the technological pillar of the Single European Sky. Its role is to define, develop and deploy what is needed to increase Air Traffic Management (ATM) performance. The SESAR Joint Undertaking (SESAR JU) was established in 2007 and is responsible for the modernisation of the European ATM system by coordinating and concentrating all ATM relevant research and innovation efforts in the EU (2).

2.1. Single European Sky

The European Commission started the SES initiative to meet the future safety and capacity needs. The first package SES I was adopted in 2004. Demanding further changes, the SES II package was adopted in 2009. The implementation of SES was promising the improvement in safety by a factor of ten, airspace capacity tripled, the reduction of costs of air traffic management by 50%, the reduction of impact on the environment of each flight by 10%.

The main idea behind SES is to transfer the design of the ATM system from a national level to the EU level. That shift would increase efficiency and reduce administrative and technical difficulties. For example, one of such concepts is implementation of Functional Airspace Blocks (FABs) as regional airspace blocks in which national air traffic providers work together to gain efficiency, cut costs and reduce emissions, but that will be explained further in the next sections (3).

The fundamental goals of the SES initiative are:

- Increasing the efficiency of air traffic management
- Reducing the fragmentation of European airspace
- Increasing the safety and efficiency of European air transport
- Modernization of ATM infrastructure
- Flexible use of airspace for civilian and military users
- New sectorization of space regardless of national borders
- Developing a coherent ATM system across Europe
- Reducing delays and congestion of the airspace
- Increase existing safety standards

- Defining the basic requirements for interoperability and encouraging the cooperation of ANSPs at regional and European level using compatible procedures
- Reduction of service prices for all airspace users (4).

The SES I package adopted in 2004 was a legislative package that comprises of four basic regulations, which reinforce safety and forward the restructuring of European airspace and air navigation services. The regulations provide the framework for the creation of additional capacity and for improved efficiency and interoperability of ATM system in Europe (1).

Implementing the provision of the SES regulations would bring a number of significant benefits:

- Improved level of safety of air navigation services.
- A more effective and integrated air traffic management architecture.
- Demand driven air navigation service provision.
- Enhanced cross-border co-ordination.
- Improved decision-making and enhanced enforcement in ATM.

Also, the concept of FABs was introduced and defined in this package, that was one of the cornerstones of the whole SES concept. FABs are vital for reducing airspace fragmentation and are necessary to deal with the traffic growth, as well as to minimise delays by managing the traffic more dynamically. Safety standards and efficiency are supposed to be achieved by increasing the scale of operations, regardless of national borders. This also implies civil-military coordination in airspace and ATM (1).

The SES I package has a delivered a number of achievements. Safety levels were raised, and safety oversight was separated from service provision. However, the SES I package has not delivered the expected results in important areas, like integration of the airspace in FABs and improvement of cost-efficiency of the European ATM network (5).

The SES II package shifts focus from increasing capacity to enhancing performances in all areas. The concept of FABs was reintroduced and further developed. The package has been put forward by the European Commission in order to make the European sky safer and more sustainable by:

- Introducing a performance framework for European ATM with quantified target setting.
- Creating a single safety framework to enable harmonised development of safety regulations and their effective implementation.
- Opening the door to new technologies enabling the implementation of new operational concept and increasing safety levels by a factor of ten.
- Improving management of airport capacity (5).

As a part of the SES II package, European Union Aviation Safety Agency's (EASA) role was expanded to supervising aerodromes, Air Traffic Management, and Air Navigation Services. Although, the agency was founded in 2002. by the European Commission for implementation of common safety rules and measures, its role expanded in 2008. and it became one of the safety pillars of the SES concept (6).

2.2. SESAR

SESAR aims to improve ATM performance by modernising and harmonising ATM systems through the definition, development, validation, and deployment of innovative technological and operational ATM solutions. These innovative solutions constitute what is known as the SESAR concept of operations (7).

The implementation of SESAR required to be distributed to several stages. The transitional period was necessary because of different states of development of ATM systems throughout Europe, difference in airline fleets and the available budgets. Therefore, the implementation was carried out in three different phases:

- A Definition phase (2005 - 2008) - in which the air traffic modernisation plan - the SESAR ATM Master Plan has been developed, establishing the different technological stages, priorities, and timetables.
- A Development phase (2008 - 2013) - development the basic technologies which will underpin the new generation of systems.
- A Deployment phase (2014 - 2020 and beyond) - large-scale installation of the new systems and the widespread implementation of the related functions (8).

The definition phase started in October 2005, under the responsibility of EUROCONTROL by a consortium of 30 members associated with more than 20 subcontractors and project associates, ANSPs, airspace users, airports, and manufacturers. Together they set out to produce six deliverables over two years, covering all aspects of the future European ATM system. Of all the deliverables perhaps the most complex, difficult, and strategically important was the delivery of a single Master Plan (9).

2.2.1. SESAR 1

SESAR 1 was the first research and development (R&D) programme that ran from 2008 to 2016. During that time 63 solutions reached maturity and were ready for implementation (10). solutions were delivered in six key areas:

- 4D Trajectory Management
- Traffic Synchronisation

- Network Collaborative Management & Dynamic/Capacity Balancing
- Initial System-Wide Information Management (SWIM)**Error! Bookmark not defined.**
- Airport Integration & Throughput
- Conflict Management & Automation (11).

SESAR 1 has successfully concluded. The next R&D programme is SESAR 2020. It is the continuation of this European research initiative, with even higher emphasis on product-orientated and solution-orientated research.

2.2.2. SESAR 2020

SESAR 2020 was launched in 2014 and planned to continue to 2024. With the budget of 1.6 billion Euros, it is focused on four key areas:

- Airport operations
- Network operations
- Air traffic services
- Technology enablers.

The research projects are categorised into three strands:

- Exploratory research,
- Industrial research and validation and
- Very large-scale demonstrations (12).

In 2019, the first wave of SESAR 2020 R&D came to a close, delivering a number of solutions and making them available for pre-industrialisation. The closure of the first wave of activities has resulted in a prioritisation of the remaining solutions, focusing on those that will bring the expected benefits by the end of the SESAR 2020 programme. This means that work has discontinued on a number of solutions. At the same time, a total of 15 projects (12 focusing on industrial research and 3 very large-scale demonstrations) will continue work in the second wave of the programme with a view to delivering a further 50 solutions (13).

2.3. ATM Master Plan

The European ATM Master Plan is set within the framework of SES. It is the planning tool for defining ATM modernisation priorities and ensuring that SESAR solutions become a reality. The Master Plan provides a high-level view of what is needed in order to deliver a high performing aviation system for Europe. It also sets the framework for the related development and deployment activities. The content of the Master Plan is structured into three levels, allowing stakeholders to view the information that is most relevant for them whether they are executives, planners or those implementing the plan. The original SESAR Master Plan was drawn up in

2008. The plan would form the foundation of the first SESAR research and development work programme (SESAR 1). Since the original document was produced, the plan has had two major updates three times, in 2012, 2015 and again in 2020, in keeping with evolutions in the ATM Landscape (9).

SESAR solutions refer to new or improved operational procedures or technologies that are designed to meet the essential operational improvements outlined in the Master Plan. Each solution is accompanied by a set of documents, available on the SESAR JU website, to support its implementation. The documentation includes:

- Operational services and environment descriptions
- Safety, performance, and interoperability requirements,
- Technical specifications,
- Regulatory recommendations,
- Safety and security assessments,
- Human and environmental performance reports,
- Relevant ICAO, and industry standards needed for implementation.

2.4. Solution Development Life Cycle

The SESAR solution lifecycle is a process executed at Project level which includes a standard sequence of activities to develop, validate and increase solution maturity. The final objective is to deliver a SESAR solution package for Industrialisation and Deployment. The SESAR solution lifecycle consists of four phases:

- V0-V1 research and definition
- V2 feasibility
- V3 implementation
- V3+ Very Large Demonstration

Activities related to the V0-V1 validation phase are executed by Projects in the domain of Exploratory Research. Some V1 activities may need to be completed by Projects in the Industrial Research and Validation domain. Activities related to the V2 validation and V3 validation phases are executed by Projects in the Industrial Research and Validation domain (14).

The SESAR solution lifecycle includes five Maturity Gates, these are decision points assessing achieved results and authorising continuation of development and validation activities along the lifecycle. Each Gate is based on a set of success criteria.

Projects will plan SESAR solution Gates in accordance with the project progress. When planning their activities, solution projects will be aware of constraints related to the Programme milestone calendar such as, the latest date for a V3 Gate allowing a SESAR solution to be part of a given release. Figure 1 shows the solution life cycle (14).

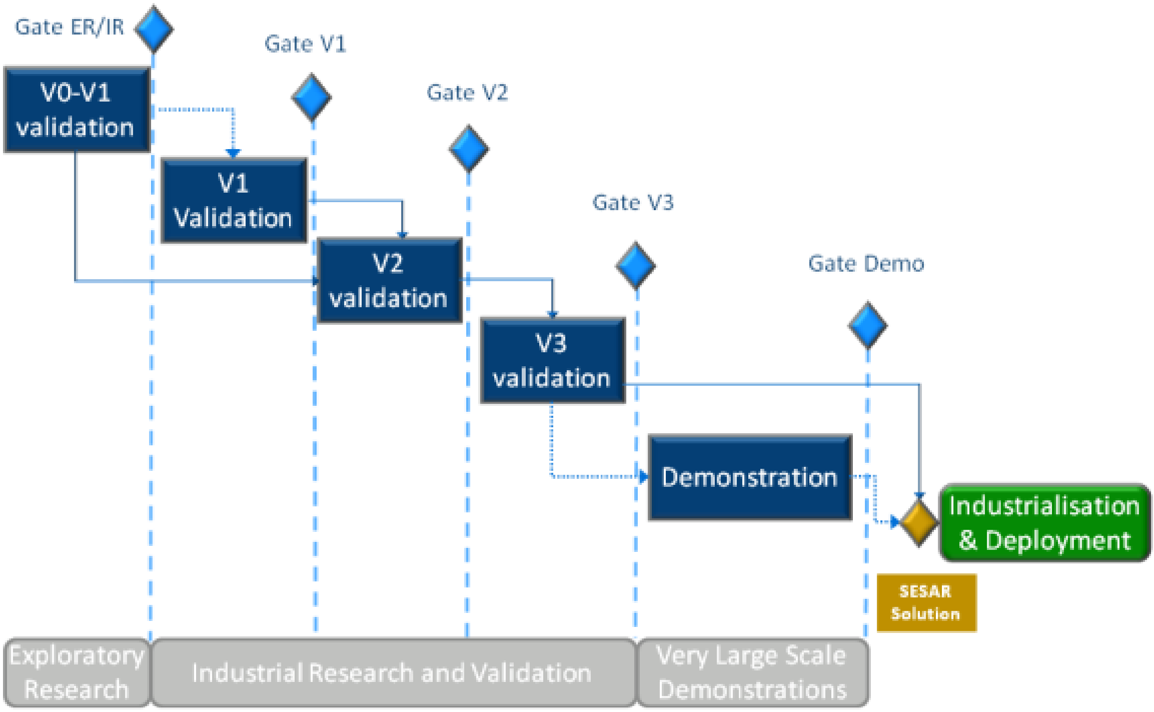

Figure 1: Phases and gates of a solution life cycle, (14)

2.5. Key Performance Areas

Key Performance Areas (KPA) are a way of categorising performance subjects related to high level ambitions and expectations (15). Key Performance Indicators (KPIs) are defined in the SESAR performance framework and relate to performance benefits in specific KPAs. Validation targets are assigned to KPIs. SESAR solutions projects use the results of validation exercises to report performance assessment in terms of the KPIs, reporting the expected positive and negative impacts (15). KPI should be selected for being specific and measurable and allowing the allocation of responsibility for achieving the performance targets.

Performance Framework is the performance-driven development approach that is applied within the SESAR Programme. It represents a framework for the support the goal of ensuring that the SESAR Programme develops the operational concept and technology needed to meet the performance ambitions described in the Master Plan. Commission Implementing Regulation (Eu) 2019/317 defines the following Key Performance Areas:

- Safety
- Environment
- Capacity and
- Cost-efficiency (16).

ATM Master Plan SESAR Performance Ambition KPA	KPI	ATM Master Plan SESAR Performance Ambition KPI
Cost efficiency	PA1	30-40% reduction in ANS costs per flight
Operational Efficiency	PA2	3-6% reduction in flight time
	PA3	5-10% reduction in fuel burn
	PA4	Arrival predictability: 2 minute time window for 70% of flights actually arriving at gate
Capacity	PA5	10-30% reduction in departure delays
	PA6	5-10% additional flights at congested airports
	PA7	System able to handle 80-100% more traffic
Environment	PA8	5-10% reduction in CO_2 emissions
Safety	PA9	Safety improvement by a factor 3-4
Security	PA10	No increase in ATM related security incidents resulting in traffic disruptions

Figure 2: Master Plan performance ambition KPAs and KPIs for 2035, (17)

Figure 2 shows Master Plan Performance Ambitions KPAs and KPIs for 2035. The performance ambitions refers to the performance capability that may be achieved if SESAR solutions are made available through Research & Innovation activities, deployed in a timely and synchronised way and used to their full potential (18).

2.6. Capacity

Challenges of Growth report by STATFOR predicts 1.5 million unaccommodated flights in 2040. With this also comes a significant increase in delays and expenses. In order to deal with the predicted traffic growth, an increase in network traffic throughput is necessary. Also, it is necessary to identify the choke points of the traffic flow to reduce delay and associated costs.

The capacity ambition, put forward in the Master Plan, is to accommodate the traffic increase predicted in the STATFORs Challenges of Growth report. The SES high level goal was to enable a threefold increase in ATM capacity. KPI used for tracking that progress were: Departure delays, IFR movements at most congested airports, Network throughput IFR flights, Network throughput IFR flight hours. Figure 3 shows the comparison of those KPI recorded in 2012 (baseline) and the defined performance ambition.

Key performance area	SES high-level goals 2005	Key performance indicator	Performance ambition vs. baseline			
			Baseline value (2012)	Ambition value (2035)	Absolute improvement	Relative improvement
Capacity	Enable 3-fold increase in ATM capacity	Departure delay[4], min/dep	9.5 min	6.5-8.5 min	1-3 min	10-30%
		IFR movements at most congested airports[5], million	4 million	4.2-4.4 million	0.2-0.4 million	5-10%
		Network throughput IFR flights[5], million	9.7 million	~15.7 million	~6.0 million	~60%
		Network throughput IFR flight hours[5], million	15.2 million	~26.7 million	~11.5 million	~75%

Figure 3: Capacity KPI, (17)

One of the problems with the capacity in the future is not just the lack of capacity, but rather lack of capacity in certain places at certain times and without the potential for growth. For example, lack of capacity of certain airports has consequences on other operational environments (OEs). Continued use of overloaded airports will have a negative impact on punctuality and predictability.

The SESAR ambition is to enable a 5-10 % capacity improvement in highly congested airports, which altogether handled 4 million movements in 2012. In addition, the overall traffic growth will encourage development of regional and local airports, supporting an increase in direct flights between European regional cities (17).

Capacity as a Validation Target for SESAR is divided in three categories: Airport Capacity (CAP3), TMA Capacity (CAP1) and En-route Capacity (CAP2). The SESAR2020 Validation Targets for Airport Capacity is set to 7% increase in peak hour throughput. The SESAR2020 Validation Target for TMA Capacity is set to 26% increase in peak hour throughput. The SESAR2020 Validation Targets for En-Route Capacity is set at a 16% increase in peak hour throughput. These figures were taken from the SESAR PJ19: Validation Targets project (19).

2.7. Safety

Safety improvements are one of the four SES high level goals fuelling the improvements of the whole ATM system. SESAR safety ambition is to have zero accidents with ATM/ANS contributions. To achieve that goal, it is assumed that the SES high level goal of the tenfold increase in safety is not enough.

A number of solutions focus specifically on improving safety. But beyond that, every solution from conception to deployment goes through safety assessments to determine its impact on safety in order to ensure they don't introduce additional risk and thus reducing the level of safety (17). Those assessments are performed using risk models, explained in the section 5.

3. Safety Performance Evaluation Process and Considering Other Aspects Related to Changes

The purpose of the Safety Performance Evaluation Process (SPEP) is to estimate the safety impact for a solution or a set of solutions. This process is based on a safety impact assessment done using risk models, in particular the Accident Incident Models in the frame of SESAR. In SESAR, this process can support:

- Definition of Safety Validation Targets (SVT) at solution level (based on SESAR Safety Ambition Goal)
- Safety Performance Assessment (SPA) at solution level and at global level

3.1. SPEP Step 1: Identification of Risk Models Impacted

Initially a qualitative review is made of the impact of each solution to be considered in order to determine the Risk Model(s) within which each solution would impact safety. Risk Models represent main types and causes of accidents and the factors that influence their risks, which is explained in detail in Section 3. To determine which Risk Model is impacted by a solution, experts working on the Project clearly specify the operational environment, services and systems preventing or contributing to the risk of an accident in relations to the solution. More than one Risk Model can be impacted by a certain solution (19).

3.2. SPEP Step 2: Quantification of the Solution Impacts

Once the relevant model(s) is/are selected, for each model it is necessary to identify the elements in the model that are impacted by each solution, that is elements in the barriers and induced events. This is done by safety experts based on relevant operational information related to each solution.

Depending on which phase of the solution life cycle the SPEP is performed, different data is available for analysis. At the V1 phase, while the solution is still in a conceptual phase, initial concept description, identification of potential benefits and risk and expert judgement is all that is available to determine a qualitative impact of a solution. At the V2 phase, elaboration and development of the operational concept are available, simulations and validation exercises are performed to represent operational contexts and to establish the concept's actual applicability. At the V3 phase, concepts are further developed to prepare their transition from research to an operational environment, prototypes are implemented into a targeted ATM system and live trials data is available for analysis (20).

The qualitative impact on the several elements of each corresponding model is then estimated by defining the percentage by which the safety performance of those elements is expected to be impacted.

The safety impact is firstly done individually for each solution. In order to define the safety impact for a set or the full range of solutions, the method applied until now was to simply add together the individual safety impact at the level of each barrier and induced event for each solution to get the total safety contribution from the set or portfolio of solutions (19).

Up to now, safety impact was calculated without taking into account relationships and interdependencies between solutions themselves. In this thesis, under the section 7 SPEP process is applied to the Runway Collision risk model and relationship impacts are explored. Using the data gathered from other KPA and relationships explored for other KPA it can be deduced that relationships between solutions have an effect on the overall solution impacts. Depending on the type of relationship, that impact can be greater, lesser, or even the same as when considering the solutions individually. When considering relationships between solutions, their safety impacts cannot be simply added together. Depending on the type of relationship between solutions, a relationship impact coefficient is calculated and applied to the safety impact. This process is explained in more detail in section 7.

3.3. SPEP Step 3: Defining the Traffic Increase to be Applied

To calculate the solution's impact on safety, it is necessary to account for traffic growth. Increasing traffic impacts safety, but the impact is not linear and depends on the type of risk (21). To estimate the impact on safety, predictions of traffic growth are to be considered mainly - but depending on each case- based on the estimated targets for capacity for the specific operational environment related to each corresponding risk model (e.g. CAP target for En route for Mid Air Collision in En route, CAP target airports for Runway Collision).

One of SESAR ambitions or high-level goals from 2005. is an increase in ATM capacity, more specifically: Airport Capacity (CAP3), TMA Capacity (CAP1) and En-Route Capacity (CAP2). These capacity increases have been used for the allocation of different Risk Models. Mid-air collision in TMA (MAC-TMA) and Controlled Flight Into Terrain (CFIT) are allocated to CAP1, Mid-air collision in En-route (MAC-ER) is allocated to CAP2 and Runway collision (RWY-Col), Taxiway collision (TWY-Col) and Wake turbulence accident in Final Approach (Wake FAP) are allocated to CAP3. The percentage of the safety benefit expected per type of accident is then calculated based on the corresponding safety benefit for each solution, taking into account the capacity SESAR Ambitions CAP1, CAP2 and CAP3 (19).

3.4. SPEP Step 4: Calculation of the Overall Safety Impact

Once the safety impact on all the elements is determined and calculated, the overall safety impact on the risk model can be calculated. For each solution, it is determined whether the solution has: a negative impact on safety, a positive impact on safety, no discernible impact on safety.

Calculations are done by processing the information using the AIM tool to obtain the safety impact. The overall safety impact is expressed in terms of “total number of accidents per year” for each type of accident individually and for all accidents with ATM contribution. Once the safety impact is calculated, taking into account the SESAR ambition increase in capacity CAP1, CAP2 and CAP3, it can be compared with the “do nothing” case in which no changes are made to ATM safety of the baseline while traffic is allowed to increase until it reaches the capacity level targeted (19).

4. Current Methods for Safety Impact Assessment of Changes and Safety Criteria Determination

As mentioned above, the SPEP can be applied for different purposes. In the frame of SESAR, it supports the:

- Definition of Safety Validation Targets (SVT) at solution level (based on SESAR Safety Ambition Goal)
- Safety Performance Assessment (SPA) at solution level and at global level

Here is an overview of these applications.

4.1. Safety Validation Targets

The main purpose of this process is to define, for a set of SESAR solutions in a wave, the corresponding Safety Validation Targets at the level of each solution in a way that the Overall Safety Target for SESAR is satisfied.

The ambition target for SESAR 2020 represents the expected reduction in the total number of estimated fatal accidents per year with ATM contributions with respect to a potential "do nothing" case outcome, in order to achieve the Safety Overall target defined for the whole SESAR, shown in figure 4. This expected safety improvement is expressed as a negative percentage as it relates to a reduction. In the "do nothing" case, no changes are made to ATM safety, while traffic is allowed to increase until it reaches the level predicted by SESAR for 2035, that is: Airport Capacity (CAP3) by 10%, TMA Capacity (CAP1) by 47% and En-Route Capacity (CAP2) by 49% (% increase in peak hour throughput) (19). It is assumed that this increase affects commercial traffic, but not VFR or military traffic, which are assumed to remain constant.

Figure 4: SESAR Overall Safety Ambition, (19)

The Validation Targets are calculated by applying the SPEP process based on the AIM model presented in section 5. Those targets are defined as well as negative percentages, expressing the reduction due to the corresponding solution in the "total number of fatal accidents per year" with ATM contribution estimated in a hypothetical "do nothing" case. The data used for the safety impact is mainly based on expert judgement and safety expectations from the ATM Master Plan.

The SVT are defined with respect to accident categories (or risk models) available AIM, the latest used release being AIM in which there were six accident categorise: Mid-air collision in En-route (MAC-ER), Mid-air collision in TMA (MAC-TMA), Runway collision (RWY-Col), Taxiway collision (TWY-Col), Controlled flight into terrain (CFIT), Wake turbulence accident in Final Approach (Wake FAP). In these categories ATM may make a significant contribution in either in causing or preventing accidents.

Once the safety impact is done for all the solutions in case the overall safety impact does not satisfy the applicable safety ambition, the process needs to be reviewed. Based on the reviewed quantification, the overall safety impact is computed again. This is an iterative process that ends once the overall safety impact satisfies the applicable safety ambition for the corresponding set of solutions (19).

4.2. Safety Performance Assessment

The purpose of safety assessment in SESAR2020 is to ensure that explicit consideration can be given at early definition and design stages to maximising the delivery of safety benefits and identifying /mitigating safety problems that could occur. It provides evidence to demonstrate that safety assessment has been conducted in a systematic way so as to be able to argue that a solution, or group of solutions, is sufficiently safe to proceed to industrialisation and deployment. In addition, at programme level, the purpose is to provide evidence that strategic safety targets are achievable.

The process that is mainly based on the Safety Validation Targets (SVT) already defined for each solution and the information from corresponding safety assessment and validation activities provided by each solution in the Performance Questionnaire and/or Performance Assessment Report. On the basis of this information, two types of measures are calculated and used to show the results:

• The process progress score: this shows progress on the safety assessment process (100% being a complete Safety Assessment at the end of V3), providing full specification at high-level system design level and corresponding evidence ensuring SVT achievability.

• The target achievability score: this measure is the combination of the SVT allocated for each solution and the process progress score described above. This means that the target achievability score is not available for all solutions, but only for those having an SVT.

Usually, for solutions that have a Safety Validation Target, solutions have a lower score using SPA than their SVT, because the SVT targets are not completely fulfilled by all solutions. Comparing those scores and the reasons behind them is called performance gap analysis. That gap can be explained by a low confidence level in the validation of safety in some solutions at V3, or by an incomplete application of the Safety Assessment Process. In V2 and V1 it is to be expected for a solution not to have yet reached the Safety Validation Target (24).

5. Supporting Tools: Risk Models

Risk models are used to calculate the potential risks of aviation accidents and provide a breakdown of their leading causes, with emphasis on ATM contributions. Accident categories are identified as models in which ATM may make a significant contribution either in causing or preventing accidents. Models show the different vulnerabilities within an ATM System and how to mitigate them. A fault tree model, or a barrier-based model, is used to represent causal factors for each accident category, including failures of its elements. The barriers are exposed to possible causes of failure and for each barrier that possible failure is expressed as a probability. The fault tree model gives an overview of how causal factors could combine to cause an accident. An accident will ensue if all of the barriers fail (20). The barrier-based risk models consist of three main parts shown in the figure 5 below. The main parts of the risk model structure are the backbone model, contributors, and the influence layer.

A risk model with contributors is the backbone model supplemented with the causal factors contributing to the main elements of the backbone. Contributors are structured in the form of a fault tree. The top event is the one of the backbone elements and it is disassembled following fault tree logic down to the base events (20). The backbone model is explained in the section 5.1.

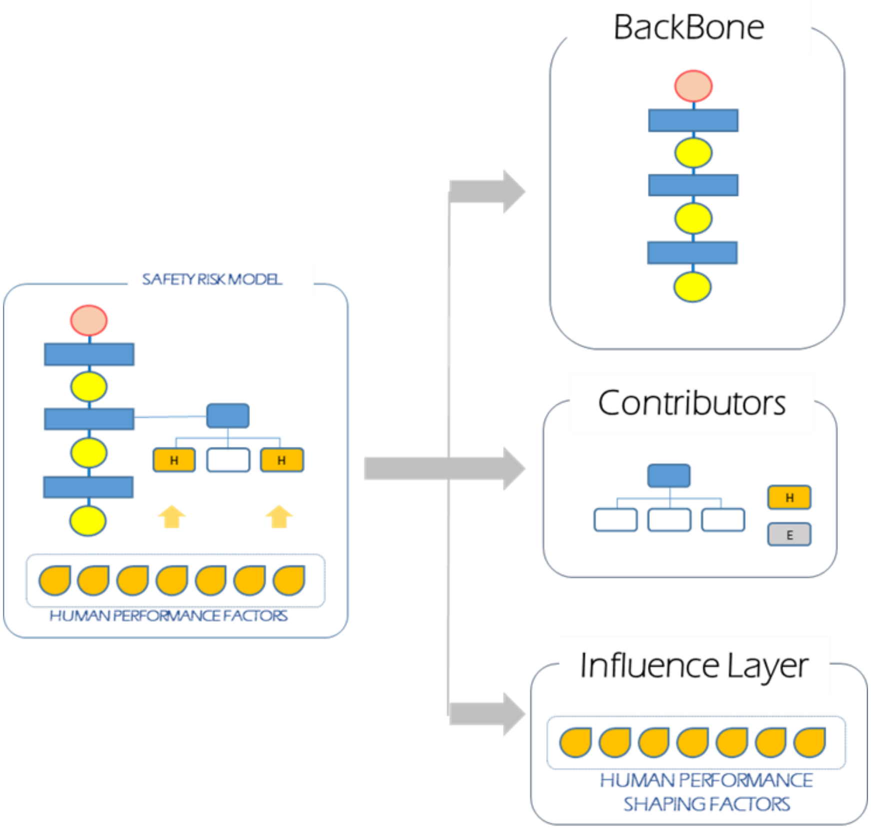

Figure 5: Main parts of the risk model, (20)

In the Safety Performance Evaluation Process only the backbone model is used to assess the impact solutions have on the overall risk. In this thesis, the emphasis is also on the backbone model since all of the assessments were performed using only that part of the structure.

5.1. The Backbone Model

The backbone is the main part of the structure of the risk models. The structure of the backbone model has three main components: precursors, barriers, and circumstantial factors. The top of the model is the event for which the model is describing the risk of, usually an accident type that is defined in the model. These elements are defined in the SAFEMODE project Risk framework (methodology) for the development of different safety models incorporating Human Factors in both transport modes, and the following definitions are quoted from that project (20).

Precursors represent real, measurable, safety statistics that describe the risk per flight hour of an ATM operation. Different precursors are recorded and measured to provide a quantitative view of the impact of safety barriers within an ATM operation. The precursor structure is largely fixed and is not changed when considering a local deployment of the models (21). They are represented in the model by the yellow ellipses. Precursors are expressed as a frequency of occurrence, mainly in flight hours. A precursor acts as the exposure to a barrier and also as the result of barrier failure being the remaining not mitigated cases. In the case that a precursor is not the result of the failure of a barrier, then it is called an induced event (20).

Barriers are the safety defences that are put in place by the network manager, ANSPs, airlines and aircraft manufactures. There are multiple layers of defence within a ground operation, from the structure of the runways and the taxiways, ground based safety nets, aircraft based safety nets and cockpit based collision avoidance system etc. Barriers have entry precursors and exit precursors and are made up of intermediate events and base events. The structure of the barriers is largely fixed (21). They are represented in the model by the light green rectangles, shown in figure 6. Barrier failures are mostly expressed as a probability.

A circumstantial factor is a condition or an attribute, with respect to time or place, that determines or modifies a precursor or the result of a causal factor. It is not strictly a causal factor but is a matter of chance that is necessary to model in order to account for specific operational situations that may have an impact on the final risk (e.g. geometrical aspects, density of traffic, etc.) (20). In the risk models Circumstantial factors are represented as grey rounded-edge rectangles. Circumstantial factors are mostly expressed as a probability.

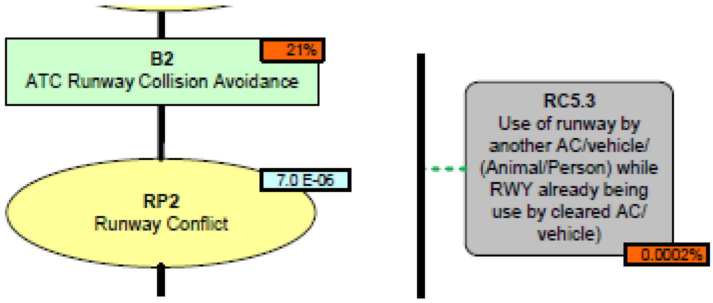

Figure 6: Barriers and induced events, (22)

The figure 6 shows a B2 barrier ATC Runway Collision Avoidance that has a 21% chance of failure, a RP2 precursor Runway Conflict with the occurrence frequency of 7.0×10^{6} flight hours and RC5.3 circumstantial factor with the 0.0002% probability of occurring. Figure 7 shows the backbone of the Runway Collision risk model. A more detailed view on the Runway Collision backbone model can be seen in Appendix A.

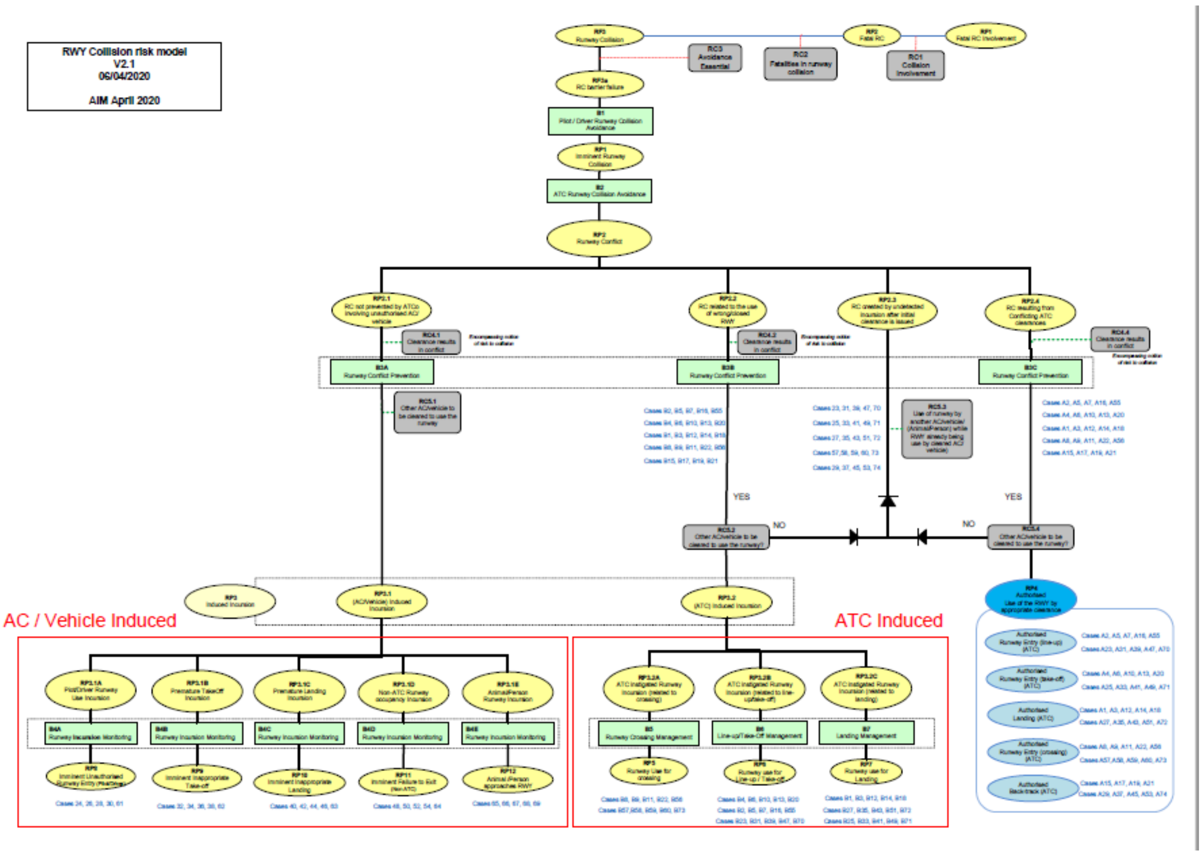

Figure 7: Runway Collision Risk Model, (22)

5.2. Quantification of Risk Models

Data types that are used for the quantification of the risk models are:

- Measured data: Taken directly from a suitable operational source or processed data, any data sources directly providing an observable measure (e.g. from processed surveillance radar data).
- Calculated data: Inferred from other values within the fault tree, following the gates logic between several elements (e.g. the barrier failure probability can be calculated from the occurrence frequencies of its entry and exit precursors.)
- Referenced data: Taken from a recognised source of data, for example, AIM ECAC values
- Expert Judgement: Based on the knowledge of recognised subject matter experts (e.g. expert working on the projects, safety experts, human factor experts) (20).

Quantification of the risk model starts with the quantification of the backbone model. Precursors are expressed in frequencies (e.g. flight/hours, flight, movements, etc.). Precursor data is an input variable and it is gathered from observations, measurements from operations, safety tools processed data, expert judgement, combined data sources.

Barrier failures, or ineffectiveness, is expressed as a probability (20). They are calculated based on the entry and exit precursors, as can be seen in the figure 8 below. The B2 ATC Runway Collision Avoidance barrier is calculated by dividing the quantification of the RP1 precursor (Imminent Runway Collision) with the RP2 precursor (Runway Conflict).

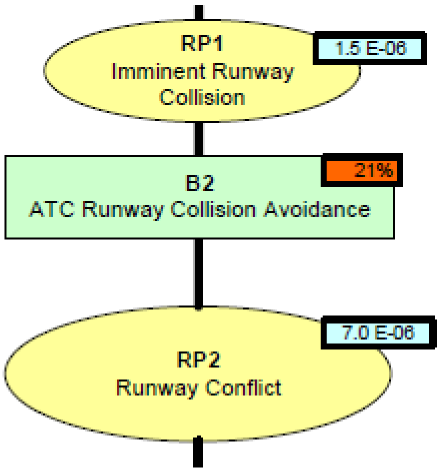

Figure 8: Quantification of barriers, (22)

For the quantification of fault trees related to induced events down to the base events, the values in the fault tree are expressed as frequencies, except in case there is an AND gate, in which in this case at least one of the children contributors has to be a probability (20).

5.3. Accident Incident Model

Accident Incident Model or AIM is a set of risk models developed in SESAR1. The AIM release 2017 encompasses six risk models, one for each accident type:

- Mid-air collision in TMA (MAC-TMA)
- Runway collision (RWY-Col)
- Taxiway collision (TWY-Col)
- Controlled flight into terrain (CFIT)
- Wake turbulence accident in Final Approach (Wake FAP)

AIM 2020 version was released, but it has not yet been used in the Safety Performance Evaluation Process for defining Safety Validation Targets or performing a Safety Performance Assessment.

The AIM risk model is used in SESAR, within SPEP, for setting quantitative safety targets that define what is considered tolerably safe for the change being introduced by a solution or a set of solutions and permit the validation of the expected safety impact of a solution (23). For SESAR it is necessary to assure that overall SESAR Safety Performance Ambition for future ATM is to be satisfied at the different concept development steps and it is essential that these targets are identified and described based on a common framework. Using AIM, it can be determined if the operational changes made by implementing the solutions have a positive, negative or no impact on safety.

The AIM risk models use the 2012 risk baseline as a reference for tracking impacts made to safety applying solution changes. That means that the total number of ATM-induced accidents and serious or risk bearing incidents, recorded in 2012., would not increase despite the expected traffic growth enabled by the solutions. The definition of "ATM contribution" includes accidents with causes that either are part of the ATM system or that ATM could reasonably have been expected to mitigate (23).

6. Potential Dependencies and Interactions Between Assessed Changes for Other KPAs

Relationships between SESAR solutions have been explored in the Performance Assessment and Gap Analysis Report (PAGAR). Those relationships were developed for other KPA, not for Safety. Possible relationships between solutions, from a deployment perspective and for other KPA, are:

- Compatible:
- Preferable (prefers, is preferable to),
- Dependant (is pre-requisite to, depends on the pre-requisite, interdependent),
- Independent (cross-effect, no cross-effect)
- Incompatible: mutually exclusive,

the relationship classification is shown in figure 9.

When it comes to relationships between solutions in regard to Safety, not all of these classifications will be used, but a detailed process is described in a dedicated section.

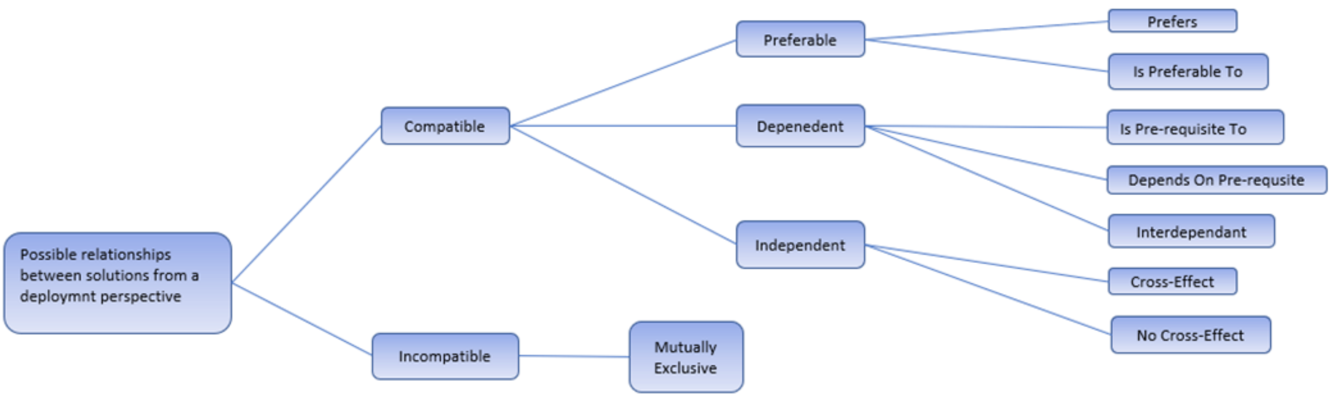

Figure 9:Relationships between solutions, (25)

For each solution, a SESAR team analyses the relationships that exist with the other solutions which have been reported by the solutions in the Performance Assessment Reports, questionnaires or during interviews. Each expert team working on the solution was requested to identify the following aspects of relationships with other solutions:

- Solution number: The PJ number of the solution with which there is an identified relationship.
- Solution title: The title of the solution with which there is an identified relationship.
- Relationship: This is the type of relationship, for example, 'Compatible – dependent – Is Pre-requisite to'.

- Justification: The justification for the relationship to describe what is the cause and the effect.
- Impacted KPA: The KPA of the solution impacted by cross-effect or preferable relationships.
- Relationship coefficient: A quantitative estimate of the scale of relationship impact between the solutions, primarily for cross-effect and preferable relationships.

If two solutions are "Independent" and have "No Cross-Effect", it is assumed that the aggregated results will be a simple sum of their safety benefit. If two solutions are "Independent" and have "Positive Cross-Effect" or are "Preferable", it is assumed that the aggregated results will be greater than the simple sum of their individual safety benefits. If two solutions are "Independent" and have "Negative Cross-Effect", it is assumed that the aggregated results will be less than the simple sum of their individual safety impact. If two solutions are "Incompatible", it is assumed that the aggregated results will not be the sum of their safety benefits as they cannot be deployed together at the same time in the same Operational Environment. For solution pairs which have "Dependent" relationship, their aggregated results could also be greater than their simple sums, but the approach cannot be generalised. If a solution is a "Pre-requisite to", it is a precondition for the deployment of the solution that depends on it and that has a relationship defined as "Depends on the Pre-requisite". Solutions with "Preferable" relationships indicate likely positive multiplier effects, for example, by benefiting from an increased access to information or reduced costs for deployment. However, this "Preferable" solution is not a necessary enabler for the deployment.

The results are grouped by KPA, but for some KPAs, such as capacity or safety, it should be noted that the results also depend on the Operational Environment in which they are deployed. For an example, capacity of high complexity airports should not be summed with the capacity of medium complexity airport, or En-route and airport safety benefits should not be aggregated together.

When assessing relationships between solutions for safety, for a specific Risk Model, for an example Runway Collision Model, relationships can have an impact on different levels. Different solutions can impact the same elements of the Risk Model, or they can impact the different elements of the same Risk Model. Also, the benefits from the relationship impact can be aggregated on two different levels. The first level is aggregating relationship impact on the level of barriers and induced events of the risk model. The second level is not applying relationship benefits at the level of barriers and induced events, but rather on the top events of the risk model. These two approaches at two different levels can have a similar impact or it can significantly differ, as will be shown later on (25).

7. Defining the New Safety Performance Evaluation Process Using the Runway Collision Risk Model

In this section the SPEP process is applied on the example of the Runway Collision risk model. The Runway Collision model was chosen for the number of solutions that impact it, the number is rather small, as ten solution from SESAR wave 2 were identified as having an impact on it. In the sections 3 and 4, generic SPEP steps and how to apply them in SESAR are explained. solutions that impact the Runway Collision model are:

- PJ02-W2-14-1 (AO-0308): Closely Spaced Parallel Runways optimised operations using Staggered Thresholds (CSPR-ST) - The Enhanced Arrival Procedures (EAP) OIs will be validating procedures in abnormal and degraded modes of operations (17).
- PJ02-W2-14-2 (AO-0319): Enhanced Arrival procedures using Second Runway Aiming Points (SRAP) - The Enhanced Arrival Procedures (EAP) OIs will mostly be trying to validate procedures in abnormal and degraded modes of operations; advance the safety case for the wake separation matrices for EAP (17).
- PJ02-W2-14-5 (AO-0331): Enhanced Arrival Procedure using an Increased Glide Slope to a Second Runway Aiming Point (IGS-to-SRAP) - The Enhanced Arrival Procedures (EAP) OIs will mostly be trying to validate procedures in abnormal and degraded modes of operations (17).
- PJ02-W2-14-10 (AO-0335): Dynamic Pairwise Runway Separations based on ground-computed arrival ROT (D-PWS-AROT) - Predicting accurate arrival runway occupancy time (AROT) separations and predicting runway exits (17).
- PJ02-W2-14-11 (AO-0336): Dynamic Pairwise Runway Separations for Arrivals (based on A/G data exchange) - This OI is complementary to the PJ02-W2-14-10 (AO-0335) and it involves predicting AROT in the cockpit (17).
- PJ02-W2-14-12 (AO-0339): Dynamic Pairwise Runway Separations for Departures (based on A/G data exchange) - This OI is complementary to the PJ02-W2-14-10 (AO-0335) and it involves predicting departure runway occupancy time (DROT) in the cockpit (17).
- PJ02-W2-14-13 (AUO-0504): Delegation of Dynamic Separation to the Aircraft – Advanced assessment of wake turbulence generated by the preceding aircraft enable flight crews to perform self-adjustments in spacing of at the phases of take-off, on initial ascend or on final approach (17).
- PJ02-W2-21-1 (AO-0104-B): Airport Safety Nets for Controllers at main airports - The R&D activity covers the development (e.g. using new algorithms, artificial intelligence /

expert systems) of procedures and required system support for an improved surface traffic management, including the extension of the Advanced Surface Movement Guidance & Control System (A-SMGCS) routing and the integration of inputs from airport DCB processes. This also covers as well the guidance assistance to both pilots and vehicle drivers using Airfield Ground Lighting (AGL), the consolidation of the Follow-The-Greens procedures, the exchange of information between ATC and vehicles/aircrafts using airport data link and other guidance means, and the development of enhanced airport safety nets for controllers beyond those delivered in SESAR 1 (17).

- PJ02-W2-21-4 (AO-0222-B): Full Guidance Assistance to mobiles using "Follow the Greens" procedures based on Airfield Ground Lighting (aprons/taxiways/runways - The R&D activity covers the development (e.g. using new algorithms, artificial intelligence/ expert systems) of procedures and required system support for an improved surface traffic management, including the extension of the A-SMGCS routing and the integration of inputs from airport Demand Capacity Balancer (DCB) processes. This also covers as well the guidance assistance to both pilots and vehicle drivers using Airfield Ground Lighting (AGL), the consolidation of the Follow-The-Greens procedures, the exchange of information between ATC and vehicles/aircrafts using airport data link and other guidance means, and the development of enhanced airport safety nets for controllers beyond those delivered in SESAR 1 (17).
- PJ05-W2-35: Multiple Remote Tower and Remote Tower Centre - The R&D activity addresses the remotely provision of Air Traffic Services (ATS) from a Remote Tower Centre (RTC) to a large number of airports. This includes the development of RTC supervisor and support systems and advanced automation functions for a more cost-efficient solution. This also covers the integration of approach for airports connected to the remote centre and connections between RTCs with systems for flow management and the development of tools and features for a flexible planning of all aerodromes connected to remote tower services (17).

These solution explanations are abbreviated and are here to get the reader familiar with the solutions used in the exercises below. The more information about the specific solutions, can be seen from official SESAR website designed for the ATM Master plan: https://www.atmmasterplan.eu/data/sesar_solutions.

7.1. Safety Impact Assessment for Each Solution Individually Without the Relationship Impact

First step of the safety impact assessment is to identify the impacted models. In this case the Runway Collision risk model was chosen beforehand. The next step is to identify barriers and induced events that are impacted in the model. The impact is estimated first qualitatively, then quantitatively. This is usually done with the help of experts working on the projects, but in this case, it was done internally using expert judgement from the safety team in EUROCONTROL by using available data related to those solutions, mainly previous results from SESAR wave 1 and description of the solutions as per the latest version of ATM Masterplan.

The figure 10 below show the quantitative assessment per element for each solution. Green highlight and the minus sign are used for the positive contributions to safety, as it relates to a risk reduction. Quantifications in red have a negative impact on safety and are a positive number as they relate to an increase in the overall risk. The total impact of the aggregation of benefits of all solutions on each element of the baseline model is shown in the last row, this aggregation does not take into account any potential relationship between solutions, but rather it is adding together, for each element in the model, the safety impact of each solution. Total per solution column shows the benefits of each solution derived from adding together all the benefits of the elements from a single solution. The impact of solution benefits on the model is calculated using the "bottom-up" approach in the AIM model.

	Barriers													Precursors								Circumstantial Factors		
SOL CODE	B1	B2	B3A	B3B	B3C	B4A	B4B	B4C	B4D	B4E	B5	B6	B7	RP4	RP5	RP6	RP7	RP8	RP9	RP10	RP11	RC5.1,2,4	RC5.3	TOTAL per solution
Baseline model	3,00%	21,739%	71,875%	74,286%	0,020%	70,588%	70,000%	58,333%	29,787%	80,000%	0,002%	0,0002%	0,0002%	1,00E+00	4,00E-01	1,00E+00	1,005E+00	1,70E-05	3,00E-06	1,20E-06	4,70E-06	50,00%	0,0002%	
PJ02-W2-14-1																		-0,01	-0,01	-0,01	-0,01			-0,04
PJ02-W2-14-2																		-0,02	-0,02	-0,02	-0,02			-0,08
PJ02-W2-14-5																				-0,05				-0,05
PJ02-W2-14-10																					-0,02			-0,02
PJ02-W2-14-11																					-0,01			-0,01
PJ02-W2-14-12																					-0,01			-0,01
PJ02-W2-14-13			-0,05	-0,05	-0,05																			-0,15
PJ02-W2-21-1		-0,05																						-0,05
PJ02-W2-21-4																		-0,01						-0,01
PJ05-W2-35		-0,02	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01											0,03
TOTAL per element		-0,07	-0,06	-0,06	-0,06	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01					-0,04	-0,03	-0,08	-0,07			
TOTAL	3,00%	20,217%	67,563%	69,829%	0,019%	71,294%	70,700%	58,917%	30,085%	80,800%	0,00230%	0,0002%	0,00023%	9,9997E-01	4,000E-01	1,000E+00	1,005E+00	1,6320E-05	2,910E-06	1,1040E-06	4,371E-06	50,00%	0,0002%	

Figure 10: Baseline quantification of the Runway Collision risk model

7.2. Defining the One-To-One Relationships Between Solutions Affecting the Same Risk Model

As previously mentioned, relationships between solutions have been explored for other KPA. With the help of safety experts from EUROCONTROL that process has been adapted to be applied to safety. Using the research done for PAGAR (Performance Assessment and Gap Analysis

Report) (25), safety experts have concluded that only some relationship types can be applied in this particular case.

The first classification remains, there are compatible and incompatible relationships. Incompatible relationships between solutions are mutually exclusive and those solutions cannot be deployed together at the same time in the same Operational Environment. For the compatible relationships between solutions, only independent relationships were identified. Independent solutions could have a greater or lesser overall safety benefit, depending if the relationship is identified as a negative or positive cross-effect. On the other hand, no cross-effect relationships also fall under the independent category and they imply that there is no interaction between those solutions and that their overall safety benefits will be a simple sum of their benefits. solutions that were identified as having a cross-effect, were also defined as having a positive or negative impact on each other, that is as having a positive or negative cross-effect relationship. For those solutions that had a positive cross-effect on each other, the aggregated results are greater than the simple sum of their individual safety benefits. For the negative cross-effect relationships, aggregated results are less than the simple sum of their individual safety benefits. Cross-effect coefficient, or as it is later on mentioned as impact coefficient, is calculated from the relationship matrix. The relationship matrix is defined by the experts working on the solutions themselves. The safety benefit obtained by a set of solutions (without relationships impact) is multiplied by the cross-effect coefficient to calculate the safety benefit with the relationship impact. The picture below shows the relationship defined for solutions impacting the Runway Collision risk model. Those relationships were defined using the already extisting relationships for other KPA and applying them for safety. In that process it was made clear that not all those previously defined relationships were applicable to this exercise. Therfore, with the help of safety experts from EUROCONTROL the following classification was defined, that is shown in figure 11.

Relationship impacts can be applied at two different levels. First level is at the level of barriers and induced events, and the second level is at the level of top elements. Safety impacts produced by these two methods vary in results, sometimes even giving a significant difference in results. But for the purpose of this exercise, it was decided to focus on the results obtained at the level of barriers and induced events.

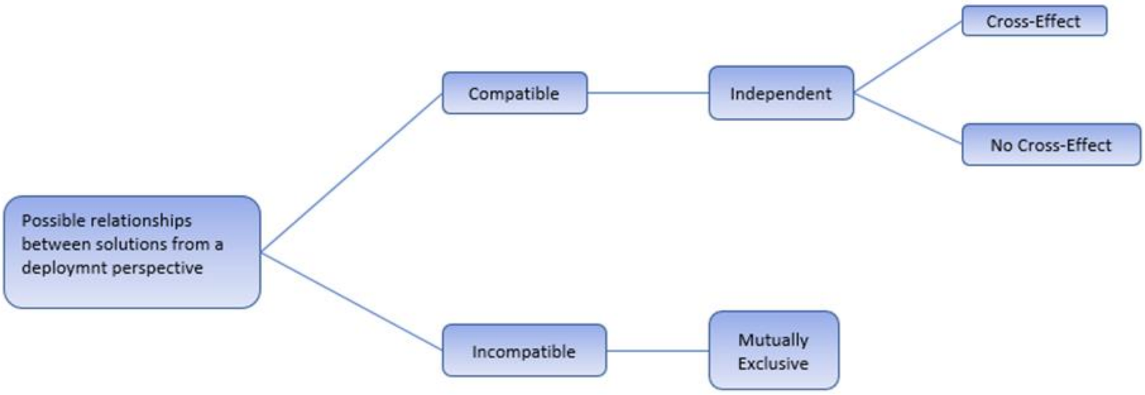

Figure 11: Relationship classification applied to safety

7.3. Defining Deployment Scenarios to Be Assessed

Having defined the relationships between solutions for the Runway Collision model it becomes clear that there are multiple solutions that are mutually exclusive and cannot be deployed at the same time, shown in figure 12. Therefore, eight different deployment scenarios were developed, to see which scenarios would provide the biggest safety improvements. Depending on the selection criteria different scenarios can be developed, such as airport type or operational environment.

x / y	PJ02-W2-14-1	PJ02-W2-14-2	PJ02-W2-14-5	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4	PJ05-W2-35
PJ02-W2-14-1		Mutually Exclusive	Mutually Exclusive	Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-2	Mutually Exclusive		Mutually Exclusive	Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-5	Mutually Exclusive	Mutually Exclusive		Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Cross Effect
PJ02-W2-14-10	Cross Effect	Cross Effect	Cross Effect		Cross Effect	Cross Effect	Mutually Exclusive	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-11	Cross Effect	Cross Effect	Cross Effect	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-12	Cross Effect	Cross Effect	Cross Effect	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-13	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ05-W2-35	Mutually Exclusive	No Cross Effect	Cross Effect	Mutually Exclusive	Mutually Exclusive	Mutually Exclusive	Mutually Exclusive	No Cross Effect	No Cross Effect	

Figure 12: Relationships between solutions

When talking about relationships in this exercise it is also necessary to re-evaluate the safety Impact assessment taking into account cluster relationships. Cluster relationships are two or more relationships that impact the same element or elements of a risk model. Cluster relationships can be taken into account at two different levels. The first level is at the level of barriers and induced events, and the second level is at the level of top elements. Safety impacts produced by these two methods vary in results, sometimes even giving a significant difference in results. But for the purpose of this exercise, it was decided to focus on the results obtained at the level of barriers and induced events. This process of defining the relationships in the cluster and their safety impact is dependent on expert judgement, involving safety experts, operational experts, and human factors experts

When only one solution impacts a certain element, it is assumed that that the impact remains the same. When two or more different solutions impact the same element and are in cross-effect, it is assumed that their impact is defined by their relationship matrix. Through that relationship matrix it is defined if their impact is greater, lower or the same as the aggregation of their individual impacts. The relationship matrix applied to the Runway Collision model can be seen in Appendix B. The potential cross-effect between different solutions affecting different elements in the model were not taken into account, that should be explored later on.

The cluster relationship at the level of each element in the model is shown as a coefficient with the respect to the addition of the impacts of all solutions. Coefficient higher than 1 means positive cross-effect of the cluster. Coefficient less than 1 means negative cross-effect. Coefficient 1 means no cross-effect at the level of elements in the model.

When taking into account the relationships at the level of the top events, benefits from all relationships in a specific Scenario were aggregated together into an average sum and the RF3, RF2 and RF1 results were divided by that average sum. Later on, it was decided to use only the results obtained by applying the relationship impact at the level of barriers and induced events.

- <u>Scenario 1</u>

Table 1: Relationships between solutions Scenario 1

y \ x	PJ02-W2-14-1	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-1		Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-10	Cross Effect		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	No Cross Effect	Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 2: Cluster impact coefficients Scenario 1

	B2	RP8	RP9	RP10	RP11
PJ02-W2-14-1		-0,01	-0,01	-0,01	-0,01
PJ02-W2-14-10					-0,02
PJ02-W2-14-11					-0,01
PJ02-W2-14-12					-0,01
PJ02-W2-21-1	-0,05				
PJ02-W2-21-4		-0,01			
Total per element	-0,05	-0,02	-0,01	-0,01	-0,05
Total per element with realtionship contr.	-0,05	-0,02	-0,01	-0,01	-0,06
Cluster 1 impact coefficient	1	1	1	1	1,17

When looking at the relationships at the level of barriers and induced events, the RP11 induced event (Imminent Failure to Exit) is the only element in which four different solutions have an impact (PJ02-W2-14-1, PJ02-W2-14-10, PJ02-W2-14-11, PJ02-W2-14-12), therefore the impact of the relationships was determined as an average sum of the benefits from the relationship matrix. Two solutions impact RP8 (Imminent Unauthorised Runway Entry (Pilot/Driver)) induced event (PJ02-W2-14-1, PJ02-W2-21-4), but they have no cross-effect, therefore their impact is a simple sum of their benefits.

- Scenario 2

Table 3: Relationships between solutions Scenario 2

y \ x	PJ02-W2-14-2	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-2		Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-10	Cross Effect		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 4: Cluster impact coefficients Scenario 2

	B2	RP8	RP9	RP10	RP11
PJ02-W2-14-2		-0,02	-0,02	-0,02	-0,02
PJ02-W2-14-10					-0,02
PJ02-W2-14-11					-0,01

PJ02-W2-14-12					-0,01
PJ02-W2-21-1	-0,05				
PJ02-W2-21-4		-0,01			
Total per element	-0,05	-0,03	-0,02	-0,02	-0,06
Total per element with realtionship contr.	-0,05	-0,03	-0,02	-0,02	-0,07
Cluster 2 impact coefficient	1	1	1	1	1,14

Same as in Scenario 1, when looking at the relationships at the level of barriers and induced events, the RP11 induced event (Imminent Failure to Exit) is the only element in which four different solutions (PJ02-W2-14-2, PJ02-W2-14-10, PJ02-W2-14-11, PJ02-W2-14-12) have an impact, therefore the impact of the relationships was determined as an average sum of the benefits from the relationship matrix. Two solutions (PJ02-W2-14-2, PJ02-W2-21-4) impact RP8 (Imminent Unauthorised Runway Entry (Pilot/Driver)), but they have no cross-effect, therefore their impact is a simple sum of their benefits.

- Scenario 3

Table 5: Relationships between solutions Scenario 3

x / y	PJ02-W2-14-5	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-5		Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-10	Cross Effect		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 6: Cluster impact coefficients Scenario 3

	B2	RP8	RP10	RP11
PJ02-W2-14-5			-0,05	
PJ02-W2-14-10				-0,02
PJ02-W2-14-11				-0,01
PJ02-W2-14-12				-0,01
PJ02-W2-21-1	-0,05			
PJ02-W2-21-4		-0,01		
Total per element	-0,05	-0,01	-0,05	-0,04
Total per element with realtionship contr.	-0,05	-0,01	-0,05	-0,041
Cluster 3 impact coefficient	1	1	1	1,03

When looking at the relationships at the level of barriers and induced events, the RP11 induced event is the only element in which more than one solution has an impact and where the interdependencies of the solutions can be inspected. Three different solutions (PJ02-W2-14-10, PJ02-W2-14-11, PJ02-W2-14-12) impact the RP11 induced event, therefore the impact of the relationships was determined as an average sum of the benefits from the relationship matrix.

- <u>Scenario 4</u>

Table 7: Relationships between solutions Scenario 4

y \ x	PJ02-W2-14-1	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-1		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-13	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 8: Cluster impact coefficients Scenario 4

	B2	B3A	B3B	B3C	RP8	RP9	RP10	RP11
PJ02-W2-14-1					-0,01	-0,01	-0,01	-0,01
PJ02-W2-14-11								-0,01
PJ02-W2-14-12								-0,01
PJ02-W2-14-13		-0,05	-0,05	-0,05				
PJ02-W2-21-1	-0,05							
PJ02-W2-21-4					-0,01			
Total per element	-0,05	-0,05	-0,05	-0,05	-0,02	-0,01	-0,01	-0,03
Total per element with realtionship contr.	-0,05	-0,05	-0,05	-0,05	-0,02	-0,01	-0,01	-0,04
Cluster 4 impact coefficient	1	1	1	1	1	1	1	1,17

When looking at the relationships at the level of barriers and induced events, in the RP8 induced event two different solutions (PJ02-W2-14-1, PJ02-W2-21-4) have an effect, but there is no cross-effect between them, therefore their impact is a simple sum of their benefits. Three different solutions (PJ02-W2-14-1, PJ02-W2-14-11, PJ02-W2-14-12) have an impact on the

RP11 induced event; therefore, the impact of the relationships was determined as an average sum of the benefits from the relationship matrix.

- Scenario 5

Table 9: Relationships between solutions Scenario 5

x / y	PJ02-W2-14-2	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-2		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-13	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 10: Cluster impact coefficients Scenario 5

	B2	**B3A**	**B3B**	**B3C**	**RP8**	**RP9**	**RP10**	**RP11**
PJ02-W2-14-2					-0,02	-0,02	-0,02	-0,02
PJ02-W2-14-11								-0,01
PJ02-W2-14-12								-0,01
PJ02-W2-14-13		-0,05	-0,05	-0,05				
PJ02-W2-21-1	-0,05							
PJ02-W2-21-4					-0,01			
Total per element	-0,05	-0,05	-0,05	-0,05	-0,03	-0,02	-0,02	-0,04
Total per element with realtionship contr.	-0,05	-0,05	-0,05	-0,05	-0,03	-0,02	-0,02	-0,05
Cluster 5 impact coefficient	1	1	1	1	1	1	1	1,23

The relationship description is the same as described for Scenario 4, but with different values in the relationship matrix: When looking at the relationships at the level of barriers and induced events, in the RP8 induced event two different solutions (PJ02-W2-14-2, PJ02-W2-21-4) have an effect, but there is no cross-effect between them, therefore their impact is a simple sum of their benefits. Three different solutions (PJ02-W2-14-2, PJ02-W2-14-11, PJ02-W2-14-12) have an impact on the RP11 induced event; therefore, the impact of the relationships was determined as an average sum of the benefits from the relationship matrix.

- Scenario 6

Table 11: Relationships between solutions Scenario 6

y \ x	PJ02-W2-14-5	PJ02-W2-14-11	PJ02-W2-14-12	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4
PJ02-W2-14-5		Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-11	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-12	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-13	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	

Table 12: Cluster impact coefficients Scenario 6

	B2	B3A	B3B	B3C	RP8	RP10	RP11
PJ02-W2-14-5						-0,05	
PJ02-W2-14-11							-0,01
PJ02-W2-14-12							-0,01
PJ02-W2-14-13		-0,05	-0,05	-0,05			
PJ02-W2-21-1	-0,05						
PJ02-W2-21-4					-0,01		
Total per element	-0,05	-0,05	-0,05	-0,05	-0,01	-0,05	-0,02
Total per element with realtionship contr.	-0,05	-0,05	-0,05	-0,05	-0,01	-0,05	-0,024
Cluster 6 impact coefficient	1	1	1	1	1	1	1,2

When looking at the relationships at the level of barriers and induced events, in the RP11 induced event two different solutions (PJ02-W2-14-11, PJ02-W2-14-12) have an effect and those solutions are in a positive cross-effect, therefore their impact is their sum of benefits multiplied by the factor from their relationship matrix..

- Scenario 7

Table 13: Relationships between solutions Scenario7

y \ x	PJ02-W2-14-2	PJ02-W2-21-1	PJ02-W2-21-4	PJ05-W2-35
PJ02-W2-14-2		No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-21-1	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect		No Cross Effect

PJ05-W2-35	No Cross Effect	No Cross Effect	No Cross Effect	

Table 14: Cluster impact coefficients Scenario 7, barriers

	B2	B3A	B3B	B3C	B4A	B4B	B4C	B4D	B4E	B5	B6	B7
PJ02-W2-14-2												
PJ02-W2-21-1	-0,05											
PJ02-W2-21-4												
PJ05-W2-35	-0,02	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Total per element	-0,07	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Total per element with realtionship contr.	-0,07	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Cluster 7 impact coefficient	1	1	1	1	1	1	1	1	1	1	1	1

Table 15: Cluster impact coefficients Scenario7, induced events

	RP8	RP9	RP10	RP11
PJ02-W2-14-2	-0,02	-0,02	-0,02	-0,02
PJ02-W2-21-1				
PJ02-W2-21-4	-0,01			
PJ05-W2-35				
Total per element	-0,03	-0,02	-0,02	-0,02
Total per element with realtionship contr.	-0,03	-0,02	-0,02	-0,02
Cluster 7 impact coefficient	1	1	1	1

In this scenario there is no cross-effect for any solutions, therefore at both levels of approach the safety impact is a simple sum of solution benefits. That can be seen in the B2 barrier (PJ02-W2-21-1, PJ05-W2-35) and RP8 induced event (PJ02-W2-14-2, PJ02-W2-21-4) where two different solutions have an impact, but they all have no cross-effect.

- Scenario 8

Table 16: Relationships between solutions Scenario 8

y \ x	PJ02-W2-14-5	PJ02-W2-21-1	PJ02-W2-21-4	PJ05-W2-35
PJ02-W2-14-5		No Cross Effect	No Cross Effect	Cross Effect

PJ02-W2-21-1	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect		No Cross Effect
PJ05-W2-35	No Cross Effect	No Cross Effect	No Cross Effect	

Table 17: Cluster impact coefficients Scenario 8, barriers

	B2	B3A	B3B	B3C	B4A	B4B	B4C	B4D	B4E	B5	B6	B7
PJ02-W2-14-5												
PJ02-W2-21-1	-0,05											
PJ02-W2-21-4												
PJ05-W2-35	-0,02	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Total per element	-0,07	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Total per element with realtionship contr.	-0,07	-0,01	-0,01	-0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Cluster 8 impact coefficient	1	1	1	1	1	1	1	1	1	1	1	1

Table 18: Cluster impact coefficients Scenario 8, induced events

	RP8	RP10
PJ02-W2-14-5		-0,05
PJ02-W2-21-1		
PJ02-W2-21-4	-0,01	
PJ05-W2-35		
Total per element	-0,01	-0,05
Total per element with realtionship contr.	-0,01	-0,05
Cluster 8 impact coefficient	1	1

When looking at the relationships at the level of barriers and induced events, in the B2 barrier two different solutions (PJ02-W2-21-1, PJ05-W2-35) have an effect, but there is no cross-effect between them, therefore their impact is a simple sum of their benefits.

7.4. Defining the Traffic Increase That Is Taken into Account

For the purpose of this exercise, all of the scenarios were developed using the 4% traffic increase. At the beginning 2%, 3% and 4% traffic increases were used, but it was shown that those different traffic increases did not have a significant impact on this study, since it was the same data just multiplied by a slightly different factor of traffic increase.

The criteria for traffic increase factor was chosen arbitrarily, but other criteria and values could have been used. Such as CAPs that were mentioned previously, or capacity in relation to the type of airport complexity. In the future, traffic increase and therefore the capacity should be investigated more closely. It should be determined what kind of capacity is being taken into account, for example is it the capacity provided by each solution in the Scenario.

7.5. Calculation of the Overall Risk for Each Scenario

Based on the safety impact of the cluster, taking into account the cluster interaction and referencing them to the results of not taking into account the cluster relationships, and taking into account the traffic increase, the overall risk is calculated using the relevant risk model, in this case the runway collision model. The RF3 results are expressed in the overall number of the Runway Collision accidents. Using the AIM model RF2 (Fatal Runway Collision) and RF1 (Fatal Runway Collision Involvement) can also be obtained, but those results are simply the RF3 results multiplied by a predefined factor and would not contribute any further significance.

Table 19: Scenario 1 results

Scenario 1	
	RF3
do nothing case	1,9494E-08
refrence w/o relationship impact	1,83888E-08
relationship impact at the lvl of elements	1,83843E-08
ratio between the referance and the rel. impact	99,976%

Table 20: Scenario 2 results

Scenario2	
	RF3
do nothing case	1,94937E-08
refrence w/o relationship impact	1,83263E-08
relationship impact at the lvl of elements	1,83218E-08
ratio between the referance and the rel. impact	99,975%

Table 21: Scenario 3 results

Scenario3	
	RF3
do nothing case	1,84377E-08
refrence w/o relationship impact	1,8437E-08
relationship impact at the lvl of elements	99,996%

ratio between the referance and the rel. impact	99,976%

Table 22: Scenario 4 results

Scenario4	
	RF3
do nothing case	1,94937E-08
refrence w/o relationship impact	1,76190E-08
relationship impact at the lvl of elements	1,76164E-08
ratio between the referance and the rel. impact	99,985%

Table 23: Scenario 5 results

Scenario5	
	RF3
do nothing case	1,94937E-08
refrence w/o relationship impact	1,75597E-08
relationship impact at the lvl of elements	1,75549E-08
ratio between the referance and the rel. impact	99,973%

Table 24: Scenario 6 results

Scenario6	
	RF3
do nothing case	1,76654E-08
refrence w/o relationship impact	1,76634E-08
relationship impact at the lvl of elements	99,988%
ratio between the referance and the rel. impact	99,985%

Table 25: Scenario 7 results

Scenario7	
	RF3
do nothing case	1,94937E-08
refrence w/o relationship impact	1,79342E-08
relationship impact at the lvl of elements	1,79342E-08
ratio between the referance and the rel. impact	100,000%

Table 26: Scenario 8 results

Scenario8	
	RF3
do nothing case	1,94937E-08

refrence w/o relationship impact	1,80432E-08
relationship impact at the lvl of elements	1,80432E-08
ratio between the referance and the rel. impact	100,000%

As can be seen in the tables above, the difference between results obtained applying the relationship impact and results obtained not applying the relationship impact is not significant. In fact, in every scenario the difference is below 1%. Such a low benefit does not justify the use of all the resources needed to obtain those results. But to have a better overview of the possible benefits from applying relationship impacts, a sensitivity analysis is needed. It is needed to conclude if such a small difference between the two cases is due to the risk model used, solutions impacting the model, or the elements in the model that are impacted.

7.6. Sensitivity Analysis

Results obtained applying relationships interactions at the level of elements in the model and results obtained without the relationship aspects do not differ significantly, as was shown in the section above Calculation of the overall risk for each scenario. To get a better overview of the relationship impact on the overall risk, sets of generic scenarios were developed. Relationship interactions were applied at the level of elements, their impact was observed separately for barriers and separately for induced events to see which parts of the Runway Collision model affect the overall risk the most. Four scenarios were taken into account for changes made in the barriers and four scenarios for changes made in the induced events. Each scenario is made up of four generic solutions, whose quantification was done arbitrarily for the purpose of the exercise. In the first scenario, for both cases, only one solution is impacting the model. In the second scenario two solutions are impacting the model and the solutions are in a positive cross-effect. In the third scenario three solutions are impacting the model and the solution cluster is in positive cross-effect. In the fourth scenario four solutions are impacting the model and the solution cluster is in positive cross-effect. In other words, in each iteration there is a one more interaction between the solutions impacting the same element of the risk model, which can be seen in tables below.

Table 27: Scenario 1 for changes made in the barriers

SOL CODE	Barriers		
	B2	B3A	B3B
Solution 1			
Solution 2			
Solution 3	-0,05	-0,05	-0,05
Solution 4			

Total per element without relationship contr.	-0,05	-0,05	-0,05
Total per element with realtionship contr.	-0,05	-0,05	-0,05
Cluster 1 impact coeficient	1	1	1

Table 28: Scenario 2 for changes made in the barriers

SOL CODE	Barriers			
	B1	**B2**	**B3A**	**B3B**
Solution 1				
Solution 2				
Solution 3		-0,05	-0,05	-0,05
Solution 4	-0,02	-0,02	-0,02	-0,02
Total per element without relationship contr.	-0,02	-0,07	-0,07	-0,07
Total per element with realtionship contr.	-0,02	-0,08	-0,08	-0,08
Cluster 2 impact coeficient	1	1,2	1,2	1,2

Table 29: Scenario 3 for changes made in the barriers

SOL CODE	Barriers			
	B1	**B2**	**B3A**	**B3B**
Solution 1				
Solution 2			-0,01	-0,01
Solution 3		-0,05	-0,05	-0,05
Solution 4	-0,02	-0,02	-0,02	-0,02
Total per element without relationship contr.	-0,02	-0,07	-0,08	-0,08
Total per element with realtionship contr.	-0,02	-0,08	-0,09	-0,09
Cluster 3 impact coeficient	1	1,15	1,15	1,15

Table 30: Scenario 4 for changes made in the barriers

SOL CODE	Barriers				
	B1	**B2**	**B3A**	**B3B**	**B3C**
Solution 1			-0,03	-0,03	
Solution 2			-0,01	-0,01	
Solution 3		-0,05	-0,05	-0,05	
Solution 4	-0,02	-0,02	-0,02	-0,02	-0,05
Total per element without relationship contr.	-0,02	-0,07	-0,11	-0,11	-0,05

Total per element with realtionship contr.	-0,02	-0,08	-0,13	-0,13	-0,05
Cluster 4 impact coeficient	1	1,1833	1,18333	1,1833	1

Table 31: Scenario 1 for changes made in the induced events

SOL CODE	Induced events			
	RP7	RP8	RP9	RP10
Solution 1				
Solution 2				
Solution 3				
Solution 4	-0,02	-0,05	-0,05	-0,05
Total per element without relationship contr.	-0,02	-0,05	-0,05	-0,05
Total per element with realtionship contr.	-0,02	-0,05	-0,05	-0,05
Cluster 1 impact coeficient	1	1	1	1

Table 32: Scenario 2 for changes made in the induced events

SOL CODE	Induced events			
	RP7	RP8	RP9	RP10
Solution 1				
Solution 2				
Solution 3		-0,02	-0,02	-0,02
Solution 4	-0,02	-0,05	-0,05	-0,05
Total per element without relationship contr.	-0,02	-0,07	-0,07	-0,07
Total per element with realtionship contr.	-0,02	-0,08	-0,08	-0,08
Cluster 2 impact coeficient	1	1,2	1,2	1,2

Table 33: Scenario 3 for changes made in the induced events

SOL CODE	Induced events			
	RP7	RP8	RP9	RP10
Solution 1				
Solution 2		-0,01	-0,01	-0,01
Solution 3		-0,02	-0,02	-0,02
Solution 4	-0,02	-0,05	-0,05	-0,05
Total per element without relationship contr.	-0,02	-0,08	-0,08	-0,08

Total per element with realtionship contr.	-0,02	-0,09	-0,09	-0,09
Cluster 3 impact coeficient	1	1,15	1,15	1,15

Table 34: Scenario 4 for changes made in the induced events

SOL CODE	Induced events			
	RP7	**RP8**	**RP9**	**RP10**
Solution 1			-0,03	-0,03
Solution 2		-0,01	-0,01	-0,01
Solution 3		-0,02	-0,02	-0,02
Solution 4	-0,02	-0,05	-0,05	-0,05
Total per element without relationship contr.	-0,02	-0,08	-0,11	-0,11
Total per element with realtionship contr.	-0,02	-0,09	-0,13	-0,13
Cluster 4 impact coeficient	1	1,18	1,18	1,18

In the figures below those two cases are shown, taking into account the ''do nothing case'', scenarios with 4% traffic increase without relationship contributions and scenarios with 4% traffic increase with relationship contributions. The percentage shows the ratio between cases with and without relationship contributions. The RF3 top event is calculated as an overall risk for each case and it remains expressed in the overall number of the Runway Collision accidents. The results are shown in tables 36 and 37.

Table 35: Scenario 1 for changes made in the barriers

Scenario 1	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,80605E-08
t.i. 4% with rel.	1,80605E-08
%	100,00%

Table 36: Scenario 2 for changes made in the barriers

Scenario 2	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,70723E-08
t.i. 4% with rel.	1,664E-08
%	97,4675%

Table 37: Scenario 3 for changes made in the barriers

Scenario 3	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,69452E-08
t.i. 4% with rel.	1,65398E-08
%	97,6076%

Table 38: Scenario 4 for changes made in the barriers

Scenario 4	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,64351E-08
t.i. 4% with rel.	1,59554E-08
%	97,0813%

Table 39: Scenario 1 for changes made in the induced events

Scenario 1	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,93869E-08
t.i. 4% with rel.	1,93869E-08
%	100,00%

Table 40: Scenario 1 for changes made in the induced events

Scenario 2	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,9268E-08
t.i. 4% with rel.	1,91848E-08
%	99,5680%

Table 41: Scenario 1 for changes made in the induced events

Scenario 3	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,92085E-08
t.i. 4% with rel.	1,91372E-08
%	99,6286%

Table 42: Scenario 4 for changes made in the induced events

Scenario 4	
	RF3
do nothing case	1,97087E-08
t.i. 4% without rel.	1,91748E-08
t.i. 4% with rel.	1,90814E-08
%	99,5130%

As can be seen above, changes made in the barriers have a higher effect on the reduction of the overall risks. Also, the relationship clusters have a higher impact when applied on the barriers, although even when applied to the barriers the relationship clusters do not make a huge contribution in comparison to the scenarios without the relationship impact.

8. Conclusion

The objective of this thesis was to explore the influence of traffic increase and relationships between solutions on the overall risk assessment. The Runway Collision risk model was used for studying such impacts.

For the analysis of the traffic impact on the overall risks, arbitrary traffic increases of 2%, 3% and 4% were taken into account. It was decided to start the process with the generic traffic increases to explore the relation between capacity increases and safety. Later on, the 4% traffic increase was the only one kept for further calculations since the only difference between those traffic increases was the factor by which the solution safety impacts were multiplied. Therefore, there was no additional significance to observing all three traffic increases through the exercises, when the difference between them had no impact on the relations between capacity and safety.

Even though the traffic impacts on the overall runway collision risk were explored, the emphasis of the exercises was put on studying relationships between solutions. The initial assumption when approaching this thesis was that relationships between solutions could have a significant impact on the overall risk assessment. Relationships between solutions were already researched by EUROCONTROL for other KPA, except on safety. Different types of relationships were identified and applied to other KPA. While applying that research to the Runway Collision risk model and its solutions, it was clear that not all the relationships identified for other KPA can be applied to safety in this case.

Relationships that were identified for the Runway Collision risk model were defined as compatible and incompatible. The incompatible relationships were identified for the solutions that were mutually exclusive. The compatible relationships were identified as independent and further classified as having cross-effect or no cross-effect. Most relationships were identified as having no cross-effect, meaning that their interactions do not change their safety impacts. Those relationships that were identified as having a cross-effect were quantified using a relationship matrix and expressed through a relationship impact coefficient. For the solutions that are mutually exclusive it is implied that they cannot be deployed at the same time in the same operational environment. Therefore, eight different scenarios were developed keeping in mind that there are no mutually exclusive solutions in the Scenarios.

The relationship impacts can be applied at two different levels in the risk model. The first is at the level of each element in the risk model, meaning at the level of barriers and induced events. The second approach is applying the relationship benefits at the level of top events (RF1, RF2 and RF3). In the second approach, the solution benefits are applied to the baseline quantifications in the AIM model without adding the relationship impacts. Then, once the top event results are available, the relationship impacts are applied. Both approaches were examined for this thesis, however it was decided to keep only the results obtained applying the relationship impacts at the level of elements in the model. That decision was based on the way relationships are applied to the top events. With that approach the interactions between solution at the level of elements and the information it provides are lost.

Using the AIM model, traffic increase of 4% was applied to each of the scenarios calculating relationship impacts. Also, as a reference, the “do nothing” case and the 4% traffic increase to scenarios without applying relationship impact were calculated. Comparing those results, it can be seen that the relationship impacts were not significant in comparison to the cases were relationship interactions were not applied, or even in comparison to the “do nothing” case. The differences between scenarios in which the relationship impacts were applied and scenarios in which the relationship impacts were not applied to were less than 1%.

Even though the results were not what was expected at first, no conclusion could be drawn on the basis of applying those relationships to only one risk model and its solutions, especially when most of the solutions affected the same elements in the model. To further understand the relationship impacts on the model, a sensitivity analysis was performed. That was done using the Runway Collision model, but the solutions used were a generic example that was quantified arbitrarily. For this analysis, a slightly different approach was used, examining two different cases. The first case was applying relationship benefits to the barriers of the model, while not making changes in the induced events. The second case was applying relationship benefits to the induced events, while not making changes to the barriers. Results of the analysis show that the relationships have a higher impact on the overall risk when applied to the barriers, rather than when applied to the induced events. These conclusions are valid only for the Runway Collision risk model for the time being.

The next step, for continuing this research, would be to study the impact of the predicted traffic increases published as performance ambitions for capacity in the ATM Master Plan. It would be beneficial to examine the impact of the predicted traffic growth on the solution benefits and on the overall risk. Another step would be to apply these relationships to other types of risk model, to see if the same findings stand when applying relationship impacts to barriers and induced events. Also, it should be pointed out that the relationship impact was applied to solutions impacting the same elements of the same risk model. In the future, it would be interesting to see how relationships affect solutions impacting different elements of the model, or relationships between solutions affecting different risk models.

APPENDIX A: Runway Collision Risk Model

Table 43: Runway Collision Risk Model Barrier IDs

Barrier ID	Barrier Name	Basline Values
B1	Pilot / Driver Runway Collision Avoidance	3%
B2	ATC Runway Collision Avoidance	21%
B3A	Runway Conflict Prevention	70%
B3B	Runway Conflict Prevention	80%
B3C	Runway Conflict Prevention	0.0002%
B4A	Runway Incursion Monitoring	70%
B4B	Runway Incursion Monitoring	70%
B4C	Runway Incursion Monitoring	60%
B4D	Runway Incursion Monitoring	30%
B4E	Runway Incursion Monitoring	80%
B5	Runway Crossing Management	0.0023%
B6	Line-up/Take-Off Management	0.0002%
B7	Landing Management	0.0002%

Table 44: Runway Collision Risk Model Precursor IDs

Precursor ID	Precursor Name	Baseline Values (Fh[1])
RF1 (Top Event)	Fatal RC[2] Involvment	2.3E-08
RF2 (Top Event)	Fatal RC	1.4 E-08
RF3 (Top Event)	Runway Collision	1.8 E-08
RF3a	RC barrier failure	4.5 E-08
RP1	Imminent RC	1.5 E-06
RP2	Runway Conflict	7.0 E-06
RP2.1	RC not prevented by ATCO involving unauthorised AC/vehicle	2.3 E-06
RP2.2	RC related to the use of wrong/closed RWY	2.6 E-06
RP2.3	RC created by undetected incursion after initial clearance is issued	1.0 E-06
RP2.4	RC resulting from Conflicting ATC clearances	1.0 E-06
RP3	Induced Incursion	3.0 E-05

[1] Fh = Flight hours
[2] RC = Runway Collision

RP3.1	(AC/Vehicle) Induced Incursion	1.6 E-05
RP3.2	ATC Induced Incursion	1.4 E-05
RP3.1A	Piot/Driver Runway Use Incursion	1.2 E-05
RP3.1B	Premature TakeOff Incursion	2.1 E-06
RP3.1C	Premature Landing Incursion	7.0 E-7
RP3.1D	Non-ATC Runway occupancy Incursion	1.4 E-06
RP3.1E	Animal/Person Runway Incursion	4.4 E-07
RP3.2A	ATC instigated Runway Incursion (related to crossing)	9.1 E-6
RP3.2B	ATC instigated Runway Incursion (related to lineup/take-off)	2.0 E-6
RP3.2C	ATC instigated Runway Incursion (related to landing)	2.25 E-6
RP4	Authorised Use of the RWY by appropriate clearance	0.99997
RP5	Runway Use for crossing	0.4
RP6	Runway use for Line-up / Take-off	1
RP7	Runway use for Landing	1.005
RP8	Imminent Unauthorised Runway Entry (Pilot/Driver)	1.7 E-05
RP9	Imminent Inappropriate Take-off	3.0 E-06
RP10	Imminent Inappropriate Landing	1.2 E-06
RP11	Imminent Failure to Exit (Non ATC)	4.7 E-06
RP12	Animal /Person approaches RWY	5.5 E-07

Table 45: Runway Collision Risk Model Circumstantial Factor IDs

Circumstantial Factor ID	Circumstantial Factor Name	Baseline value
RC1	Collision Involvement	x 1.67
RC2	Fatalities in runway collision	x 0.75
RC3	Avoidance Essential	40%
RC4.1	Clearance results in conflict	40%
RC4.2	Clearance results in conflict	50%
RC4.4	Clearance results in conflict	1%

RC5.1	Other AC/vehicle to be cleared to use the runway	50%
RC5.2	Other AC/vehicle to be cleared to use the runway	50%
RC5.3	Use of runway by another AC/vehicle/ (Animal/Person) while RWY already being use by cleared AC/vehicle)	0.0002%
RC5.4	Other AC/vehicle to be cleared to use the runway	50%

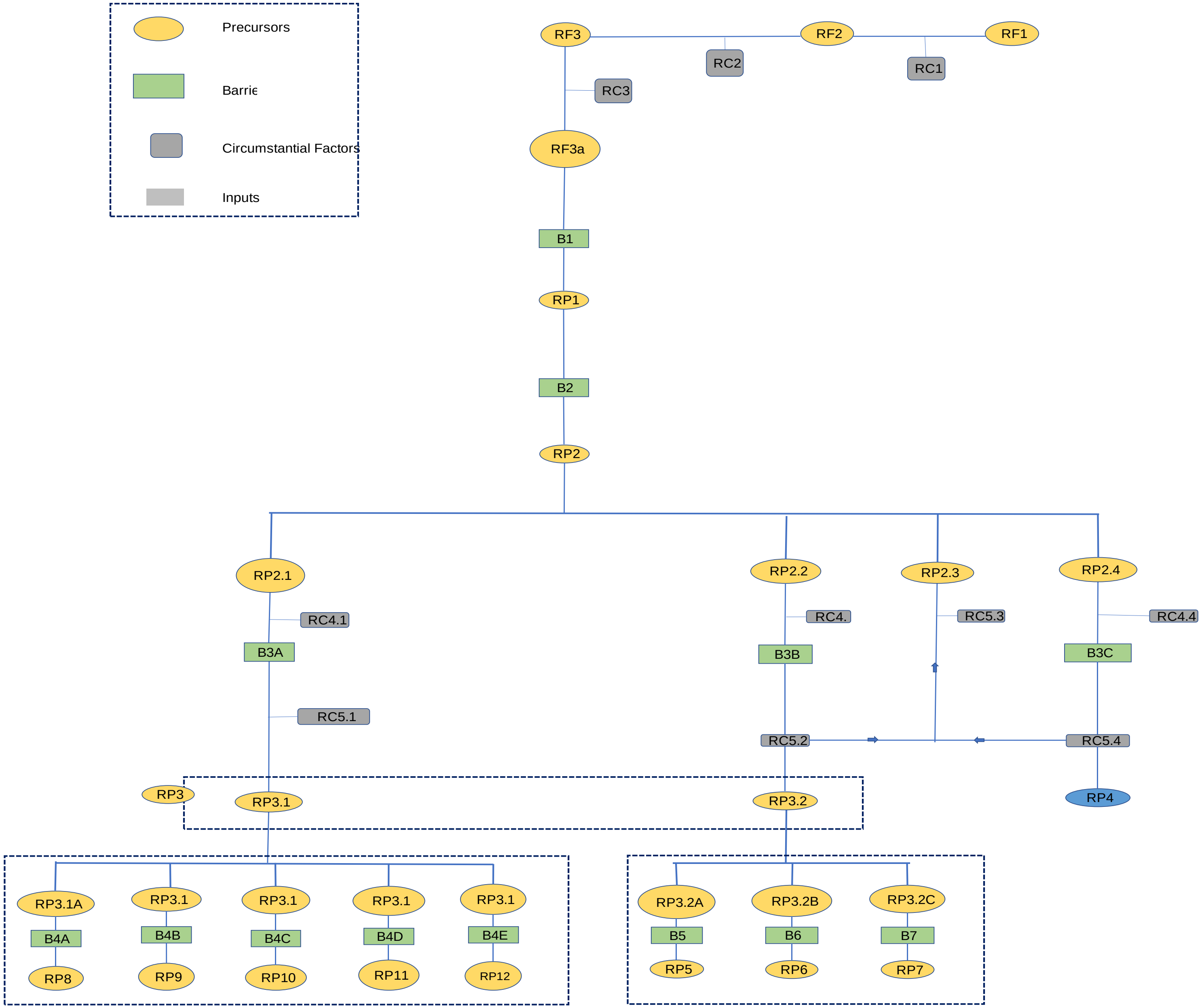

Figure 13: Runway Collision Backbone Risk Model

APPENDIX B: Relationship Matrix

y \ x	PJ02-W2-14-1	PJ02-W2-14-2	PJ02-W2-14-5	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-1	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4	PJ05-W2-35
PJ02-W2-14-1		Mutually Exclusive	Mutually Exclusive	Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-2	Mutually Exclusive		Mutually Exclusive	Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect
PJ02-W2-14-5	Mutually Exclusive	Mutually Exclusive		Cross Effect	Cross Effect	Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Cross Effect
PJ02-W2-14-10	Cross Effect	Cross Effect	Cross Effect		Cross Effect	Cross Effect	Mutually Exclusive	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-11	Cross Effect	Cross Effect	Cross Effect	Cross Effect		Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-12	Cross Effect	Cross Effect	Cross Effect	Cross Effect	Cross Effect		No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-14-13	No Cross Effect	No Cross Effect	No Cross Effect	Mutually Exclusive	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect	Mutually Exclusive
PJ02-W2-21-1	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect	No Cross Effect
PJ02-W2-21-4	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect	No Cross Effect		No Cross Effect
PJ05-W2-35	Mutually Exclusive	No Cross Effect	Cross Effect	Mutually Exclusive	Mutually Exclusive	Mutually Exclusive	Mutually Exclusive	No Cross Effect	No Cross Effect	

y \ x	PJ02-W2-14-1	PJ02-W2-14-2	PJ02-W2-14-5	PJ02-W2-14-10	PJ02-W2-14-11	PJ02-W2-14-1	PJ02-W2-14-13	PJ02-W2-21-1	PJ02-W2-21-4	PJ05-W2-35
PJ02-W2-14-1				1,3	1,2	1,4	1	1	1	
PJ02-W2-14-2				1,25	1,3	1,2	1	1	1	1
PJ02-W2-14-5				0,75	0,6	1,2	1	1	1	0,9
PJ02-W2-14-10	1,3	1,25	1,2		0,7	1,2		1	1	
PJ02-W2-14-11	1,2	1,3	0,6	0,7		1,2		1	1	
PJ02-W2-14-12	1,4	1,2	1,2	1,2	1,2			1	1	
PJ02-W2-14-13	1	1	1		1	1		1	1	
PJ02-W2-21-1	1	1	1	1	1	1	1		1	1
PJ02-W2-21-4	1	1	1	1	1	1	1	1		1
PJ05-W2-35		1	0,9					1	1	

Figure 14: Relationship matrix applied to solution in the Runway Collision risk model

LITERATURE

1. SKYbrary, Available from: https://www.skybrary.aero/index.php/Single_Europea [Accessed: August, 2020]
2. SESAR JU, Available from: https://www.sesarju.eu/discover-sesar/history, [Accessed: August, 2020]
3. European Commission, Available from: https://ec.europa.eu/commission/presscorner/detail, [Accessed: August, 2020]
4. Petrović M., Simulation of Merging Airspaces of Macedonia, Albania and Kosovo with South East Common Sky Initiative Free Route Airspace, Zagreb: Faculty of Transport and Traffic Sciences, 2019
5. SKYbrary, Available from: https://www.skybrary.aero/index.php/Single_European_Sky_(SES)_II, [Accessed: August, 2020]
6. SKYbrary EASA, Available from: https://www.skybrary.aero/index.php/European_Union_Aviation_Safety_Agency_(EASA) [Accessed: August, 2020]
7. European Commission, Available from: https://ec.europa.eu/transport/modes/air/sesar_en, [Accessed: August, 2020]
8. SKYbrary SESAR, Available from: https://www.skybrary.aero/index.php/SESAR, [Accessed: August, 2020]
9. Walinskas K. From vision to reality, SESAR JU, 2016
10. SESAR JU. SESAR Solutions Catalogue 2019. 3rd Ed.
11. Juričić B. Upravljanje Kapacitetom I Međunarodna i nacionalna regulativa i legislativa, Fakultet prometnih znanosti, 2020
12. SESAR JU, Available from: https://www.sesarju.eu/activities, [Accessed: August, 2020]
13. SESAR JU, Available from: https://www.sesarju.eu/index.php/news/first-wave-sesar-2020-comes-close, [Accessed: August, 2020]
14. Framework PE. Introduction to the SESAR 2020 Programme Execution., EUROCONTROL, 2015

15. PJ19 : Performance Framework, SESAR, EUROCONTROL, 2019

16. Commission Implementing Regulation (EU) 2019/317, European Commission, 2019

17. European ATM Master Plan, 2020 Edition, 2020

18. SESAR Performance Framework, SESAR, EUROCONTROL, A Common Programme Reference for Performance Management, 2019

19. PJ19.04.01 D4.2 Validation Targets (2019), SESAR, EUROCONTROL, Edition 00.00.03, 2020

20. SAFEMODE, EUROCONTROL, Risk Framework (Methodology) for the Development of Different Safety Models Incorporating Human Factors in Both Transport Modes, Version 1.1, 2020

21. IRP 2009 Main Report, EUROCONTROL, SESAR Top-Down Systemic Risk Assessment, 2010

22. Accident Incident Models, EUROCONTROL, 2020

23. Project Execution Guidelines for SESAR 2020 VLD demonstrations awarded under Open Calls, SESAR, EUROCONTROL, Version 1.00.00, 2016

24. Safety support and coordination function, SESAR, EUROCONTROL, Guidance to Apply the SESAR Safety Reference Material, Edition 00.03.00, 2019;

25. Relationship excerpt from Performance Assessment and Gap Analysis Report (2019), SESAR, EUROCONTROL, Edition 00.01.02, 2019

List of Abbriviations

AGL - Airfield Ground Lightning, 35

AIM - Accident Incident Model, 24

ANSP - Air Navigation Service Provider, 10

AROT - Arrival Runway Occupancy Time, 34

A-SMGCS - Adanced Surface Movement Guidance & Control System, 35

ATC - Air Traffic Control, 10

ATM - Air Traffic Management, 8

ATS - Air Traffic Services, 35

CAP1 - TMA Capacity, 17

CAP2 - En-route Capacity, 17

CAP3 - Airport Capacity, 17

CFIT - Controlled Flight into Terrain, 25

CSPR-ST - Closely Spaced Parallel Runways, 34

DCB - Demand Capacity Balancer, 35

D-PWS-AROT - Dynamic Pairwise Runway Separation based on ground computed arrival ROT, 34

EAP - Enhanced Arrival Procedure, 34

EASA - European Union Aviation Safety Agency, 11

FAB - Functional Airspace Block, 8

IGS-to-SRAP - Glide Slope to Second Runway Aiming Point, 34

KPA - Key Performance Area, 15

KPI - Key Performance Indicator, 15

MAC-ER - Mid-Air Collision in En-route, 24

MAC-TMA - Mid-Air Collision in TMA, 24

NSA - National Supervisory Authorities, 10

OE - Operational Environment, 17

PAGAR - Performance Assessment and Gap Analysis Report, 32

R&D - Research and Development, 11

RTC - Remote Tower Center, 35

RWY-Col - Runway Collision, 24

SES - Single European Sky, 8

SESAR - Single European Sky ATM Research, 8

SESAR JU - SESAR Joint Undertaking, 8

SPA - Safety Performance Assessment, 26

SPEP - Safety Performance Evaluation Process, 26

SRAP - Second Runway Aiming Point, 34

SVT - Safety Validation Targets, 26

SWIM - System Wide Information Management, 12

TWY-Col - Taxiway Collision, 24

Wake FAP - Wake Turbulence Accident in Final Approach, 25

List of Figures

List of Tables

University of Zagreb
Faculty of Transport and Traffic Sciences
10000 Zagreb
Vukelićeva 4

DECLARATION OF ACADEMIC INTEGRITY AND CONSENT

I declare and confirm by my signature that this master's thesis
is an exclusive result of my own work based on my research and relies on published literature, as can be seen by my notes and references.
I declare that no part of the thesis is written in an illegal manner,
nor is copied from unreferenced work, and does not infringe upon anyone's copyright.
I also declare that no part of the thesis was used for any other work in
any other higher education, scientific or educational institution.
I hereby confirm and give my consent for the publication of my master's thesis
titled Development of a Safety Performance Evaluation Process and Supporting Tool for Changes in ATM
on the website and the repository of the Faculty of Transport and Traffic Sciences and
the Digital Academic Repository (DAR) at the National and University Library in Zagreb.

Student:

In Zagreb, 10 September 2020 Tea Dobroslavić

(signature)