EXPLORATORY RESEARCH

Project Results Final Report

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BEST

Achieving the BEnefits of SWIM by making smart use of Semantic Technologies

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699298 under the European Union's Horizon 2020 research and innovation programme.

Abstract

This document describes the challenges addressed by the BEST project, the achievements made in the project, and possible next steps/impact.

Further details, including the full text of project deliverables (and summaries thereof), information about how to access technical results of the project (software and ontologies), and a short video explaining some technical details of parts of the work, are available on the project website at:

http://project-best.eu/

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Purpose of this Document

The document is intended to address a wide audience of ATM stakeholders, to explain what the project set out to do, what was achieved in the project, what relevance this may have in future for ATM stakeholders, and what further research in the area may be useful.

1 Executive Summary

BEST (**A**chieving the **BE**nefits of SWIM by making smart use of **S**emantic **T**echnologies) was a SESAR Exploratory Research project that looked at how semantic technologies could be used to help promote SWIM (System Wide Information Management). Its objectives addressed research questions about use of semantic technologies to handle metadata, achieving scalable solutions, automated compliance checking using ontology matching, optimisation of data distribution and the use of automated modularisation and its implications for governance.

The main results of the project were:

- The "semantic container" concept. Semantic containers can be combined with SWIM services to associate meta-data with ATM information, making it easier to find exactly the information required, and to automate its distribution and replication.
- Scripts to automatically generate ontology representations of the AIRM and the AIXM data exchange model.
- A compliance validator tool that uses ontology matching to (partially) automate the process of checking compliance.
- Tool to allow an ontology to be broken down into smaller modules, using different criteria for doing the modularisation.
- Recommendations on scalability, modularisation and governance.

The project contributes to the SESAR ATM master plan in the area of facilitating aeronautical data exchanges (IS-0204 oi/EN). It fulfils SESAR requirements for a TRL 1 project.

A key conclusion of the project is that semantic ontologies can be applied to the domain of ATM information management; benefits include easier ways for services to obtain the precise information needed, reduced information overload, automated compliance checking, automated modularisation (with positive implications for governance).

Detailed "lessons learned" were extracted from all the technical areas of the project. Future work in the area should be based not only on further development and application of specific results (with a focus on the semantic container concept, the compliance validator, and modularisation/governance) but also on widening the scope and applicability of the results to other domains .

Further details, including the full text of project deliverables (and summaries thereof), information about how to access technical results of the project (software and ontologies), and a short video explaining some technical details of parts of the work, are available on the project website at:

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2 Project Overview

2.1 Operational/Technical Context

The picture illustrates the motto of the BEST project: **OWL meets SWIM**. OWL is the name of a well-known language used in the field of semantic technologies. SWIM [4] means System Wide Information Management, and is a concept promising a complete change in the way ATM information is managed. These two "meet" in BEST, because the project is all about:

Achieving the **BE**nefits of SWIM by making smart use of **S**emantic **T**echnologies.

SWIM is one of the major results of the original SESAR project, and moves within the ATM community to adopt it will lead to dramatic changes in how ATM services will be provided. Traditional ATM information management was based on point-to-point message transfer, meaning information producers had to decide in advance who the target recipients would be. SWIM will change all this because it is based on the *information sharing* approach where information producers do not need to know anything about who might use the information, and where information consumers can access information from different sources as they please.

Another result of the original SWIM project is AIRM, the ATM Information Reference Model, which complements SWIM by providing a standardized "vocabulary" to facilitate development of interoperable applications sharing information.

However, SWIM and AIRM do not in themselves guarantee the common situational awareness that is the ultimate aim of ATM information management. For that to be achieved, ways need to be found to avoid information overload and ensure that all involved parties receive just the information they need, just when they want it, with appropriate metadata about provenance, freshness etc. Achieving that needs extra support beyond the basic infrastructure provided by the SWIM concept.

Semantic technologies provide modelling techniques, languages and tools that allow development of software to process and "understand" information designed ultimately for human perception. The basic premise of BEST is that such semantic technologies could be used to complement what is provided in SWIM in order to enhance how SWIM can be used for truly effective information management. The main objective of the BEST project is ***to determine how semantic technologies can be used effectively to maximise the benefits of adopting SWIM.*** There is no tradition in ATM of using semantic technologies, and even some scepticism amongst some about their applicability. So, it was a rather ambitious objective that the project set itself at its outset. Has the project succeeded? Read on….

2.2 Project Scope and Objectives

Being an exploratory research project, BEST formulated its objectives as a set of key ***research questions.*** The set of questions defines the scope of the project. It is providing answers to each of these questions that constitute the objectives of the project, and the technical results of the project were produced as a means to answer the questions.

The summary figure on the following page shows all the research questions (drawn as clouds), and how they fit together with the results produced (drawn as ovals). The sections which follow "zoom in" on this diagram, and take each research question in turn, explaining in more detail what the project set out to do to answer the question.

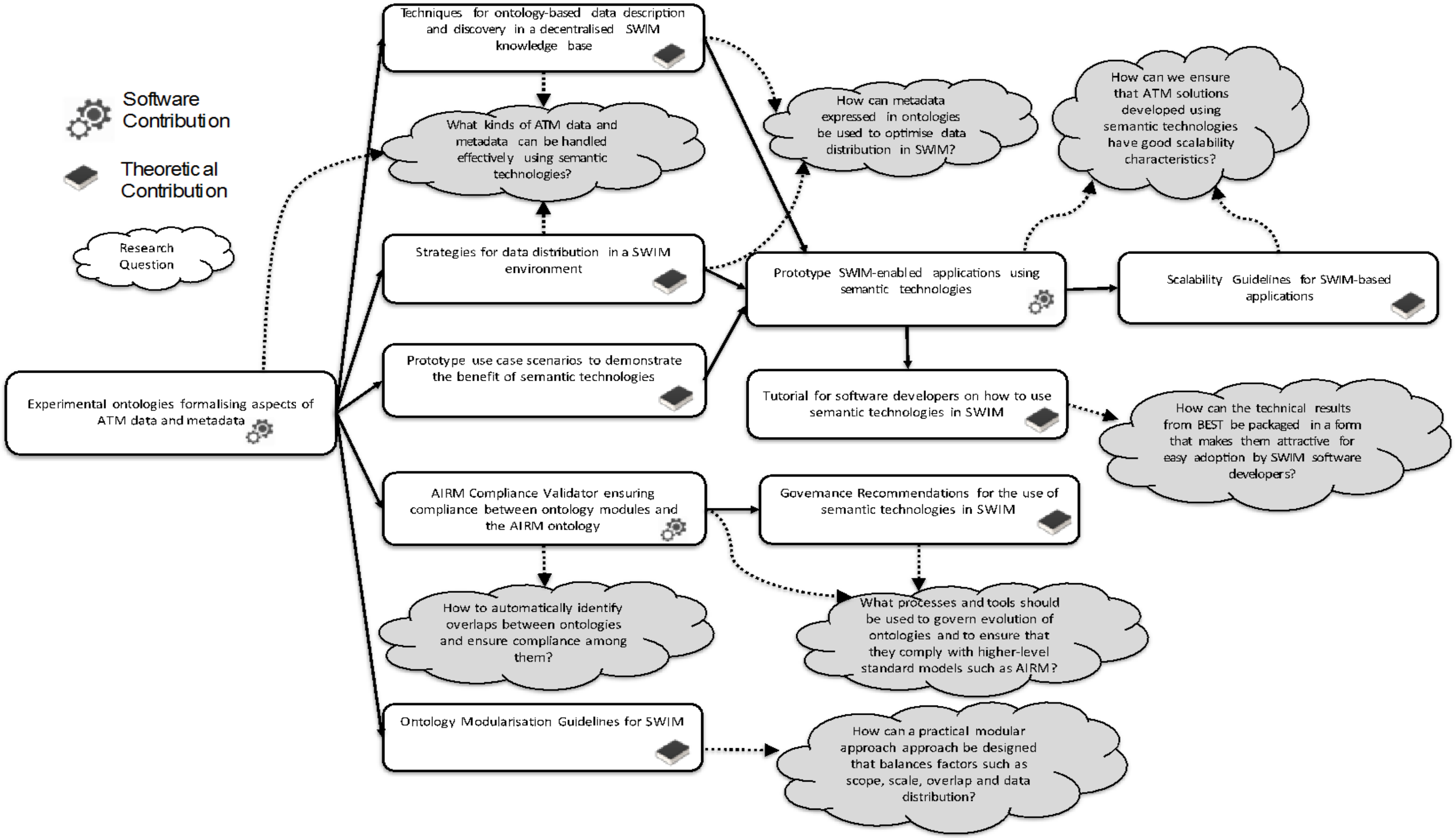
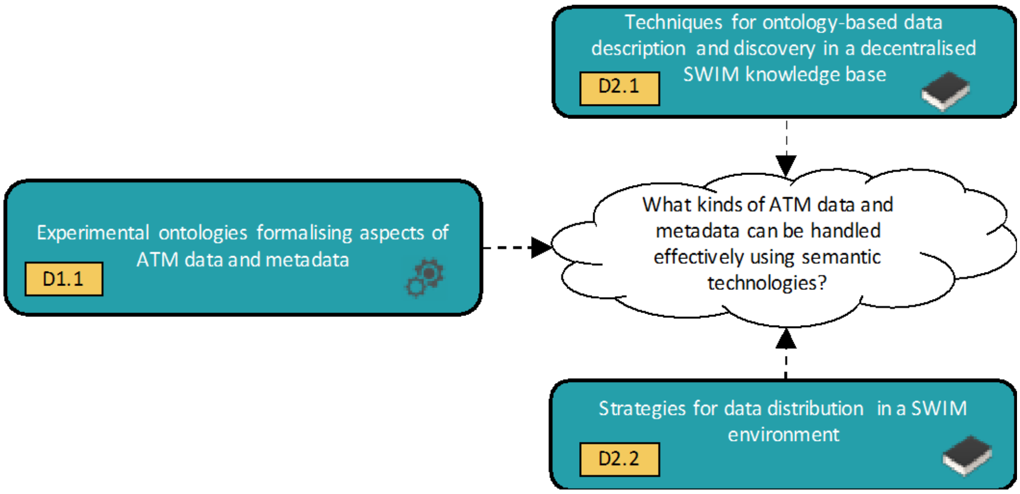


Figure 1: Overview of BEST research questions and main results

2.2.1 What kinds of ATM data / metadata can be handled effectively using semantic technologies, enabling composition and filtering of data, and so producing innovative ATM applications?

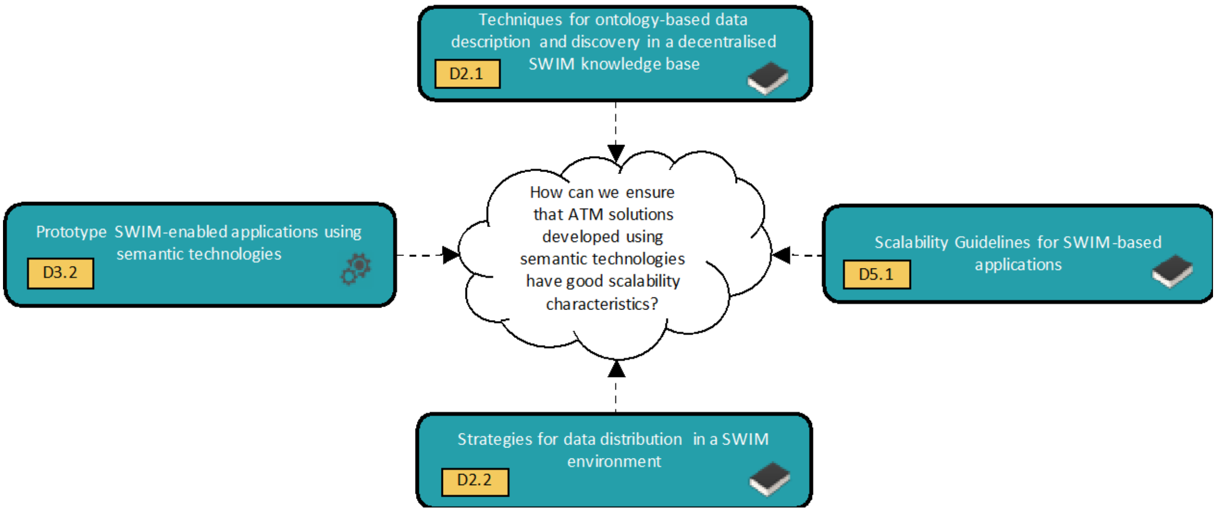
ATM information models describe the semantics of information exchanged in ATM. In the BEST project we have focused on the ATM Information Reference Model (AIRM), the Aeronautical Information Exchange Model (AIXM) and the ICAO Meteorological Information Exchange Model (IWXXM). AIRM is a reference model for semantics, while AIXM and IWXXM are exchange models that describe the digital format used when exchanging aeronautical and meteorological information between ATM information systems. After having identified these information models, ontologies that express concepts for the ATM domain were developed in BEST (deliverable D1.1). Ontologies are a fundamental part of the semantic technology stack. BEST makes extensive use of them.

These ontologies were transformed to from standardised ATM information models using software developed in BEST. They are then used as the vocabulary for the metadata used to describe ATM information offered by semantic containers (techniques for implementing semantic containers are defined in deliverable D2.1). Semantic containers complement SWIM services in the sense that they provide semantic descriptions of the information that a SWIM service offers to end-users and through this facilitate retrieval of relevant ATM information (while disregarding irrelevant information). Furthermore, the semantic container approach allows for caching the information so that it easily can be re-used. BEST further developed data distribution and consistency management strategies that describe how ATM information should be exchanged, supported by semantic containers. These strategies were formulated in deliverable D2.2.



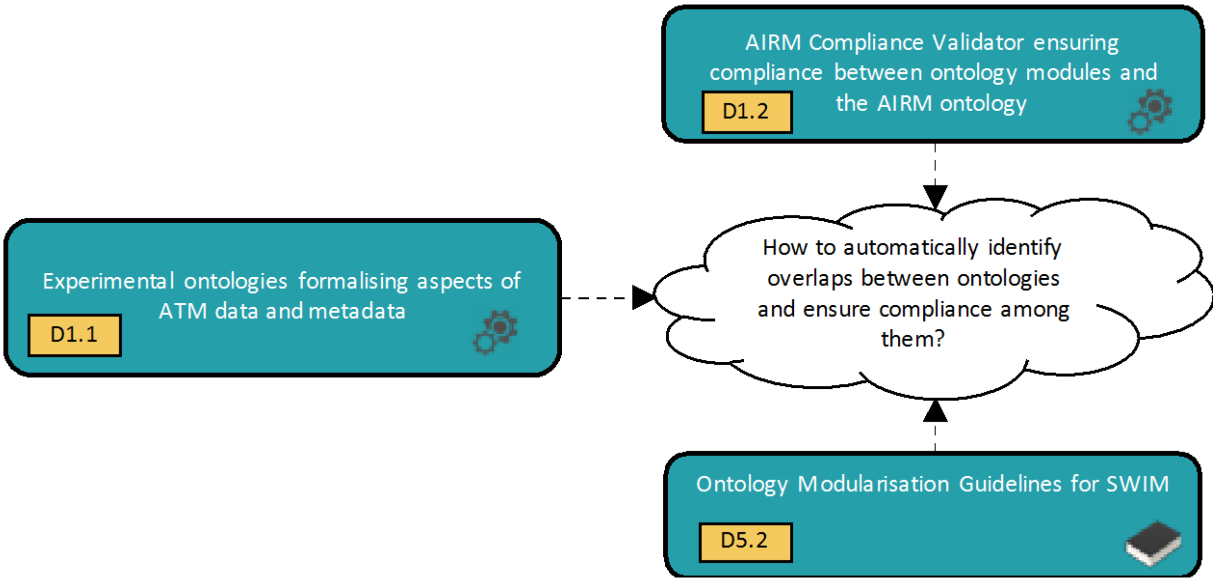
2.2.2 How can we ensure that ATM solutions developed using semantic technologies have scalability characteristics that allow them to be used successfully even when data volumes, complexity and load increase?

Scalability is an important prerequisite for any usable software applications. Deliverable D5.1 investigated which scalability characteristics relate to semantic technologies and their application in SWIM. The outcome of this deliverable was a set of guidelines that enable an understanding of how scalability can be analysed in the application of semantic containers (D2.1, D2.2, and D3.2).



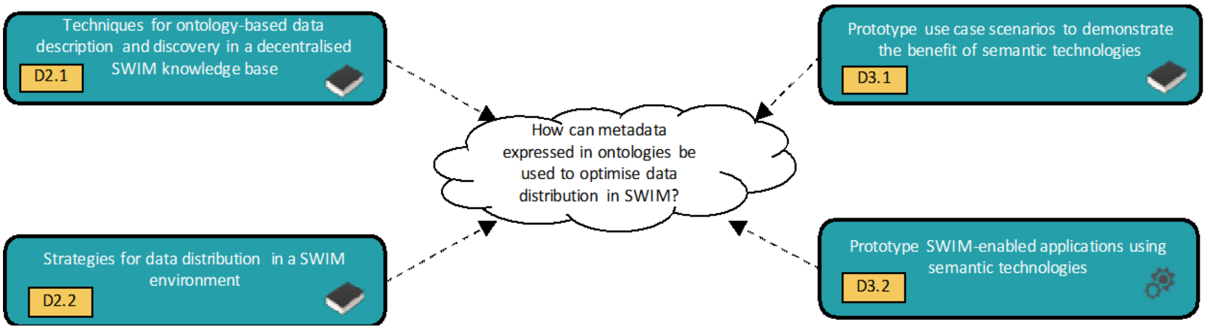
2.2.3 How can ontology matching be used to automatically identify overlaps between ontologies and ensure compatibility among them?

If semantic interoperability is to be accomplished in ATM, it is crucial that information models in this domain are in compliance with the AIRM. However, ensuring compliance between such large monolithic models, often encompassing diverse sub-domains (e.g. meteorology) is challenging. The BEST project suggests a modular approach in the sense that monolithic models are decomposed into smaller parts and that the dependencies between these parts are clearly defined. One assumption made by the project is that such a decomposition would also simplify and strengthen governance activities. The AIRM Compliance Validator is a proof-of-concept application developed in deliverable D1.2 that can support compliance verification through a partly automated process. This application was evaluated using ontologies developed in D1.1 and ontology modules developed in deliverable D5.2.



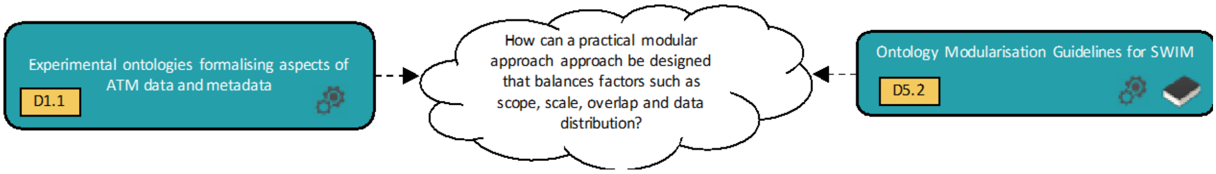
2.2.4 How can metadata expressed in ontologies be used to optimise SWIM data distribution (e.g. to influence replication strategies)?

ATM information packaged into the semantic containers described in D2.1 can be stored redundantly on different server nodes for increased availability. Deliverable D2.2 describes how metadata expressed using semantic technologies allows for the replication of information and the subsequent discovery and re-use in a distributed environment. A semantic container may also derive from other containers, combining the information contained in these containers. The semantic description of information allows for the updating of such combinations of containers in a distributed environment where different services produce and update the source information. The semantic description may also be beneficial for deciding where to allocate information in a distributed SWIM environment. Deliverable D3.1 illustrates how data distribution in ATM can be optimised using semantic containers, and deliverable D3.2 demonstrates practical use of the semantic container concept in proof-of-concept applications.



2.2.5 In order to (ultimately) provide ontology-based modelling of the full breadth of all ATM information, how can a practical modular approach be designed that balances factors such as scope, scale, overlap and data distribution?

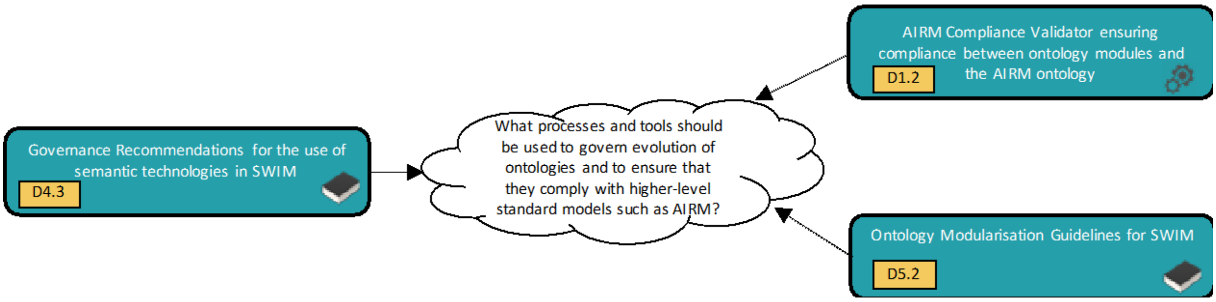
Deliverable D5.2 provides guidelines on how to extract ontology modules from the ATM ontologies developed in D1.1. The ontologies developed in D1.1 are large in size and complex in structure and will, in many cases, include more concepts, properties and instances than needed for a particular use case. Ontology modules on the other hand represent subsets of these initial ontologies that can be customised to encompass only the entities required for describing a single knowledge domain and/or a particular purpose. Ontology modularisation is a process whereby ontology modules are automatically obtained from larger ontologies using a variety of techniques. The rationale for operating with modules instead of their monolithic counterparts can be, for example, improved performance, usability and maintainability. Supported by a well-established theoretical framework, D5.2 recommends a set of step-by-step guidelines combining theoretical principles for ontology modularisation with lessons learned from the modularisation efforts performed in the BEST project. As part of the work in D5.2 we have developed a set of software tools to support the modularisation process. These tools are available from github at: https://github.com/sju-best-project/ontology-modules



2.2.6 What processes and tools should be used to govern evolution of ontologies, and to ensure that they comply with higher-level standard models such as AIRM?

If we are to use ontologies as part of an overall strategy for information management, it is essential that these become standardised in some way – with the full support and buy-in of relevant stakeholders. This implies that we need an approach to governance (i.e. processes for making decisions about changes to ontologies) that is transparent, representative and efficiently managed. It is also essential that ontologies are fully consistent with other applicable standards (such as AIRM) that may be expressed using means other than ontologies.

The BEST approach to this research question is based on developing two technical foundations: (1) A tool to help automate the process of checking consistency between models, including the AIRM. This is provided by D1.2, the compliance validator. (2) Automated tool support to help split ontologies into smaller, more easily managed modules. This is provided by D5.2. Based on experience of building and testing these technical results, BEST addresses the governance issue by providing recommendations and guidelines – in D4.3.



2.3 Work Performed

So how was the task of answering all these questions organised in BEST?

The approach is illustrated in the diagram below, showing the break-down into work packages. The core technical work was carried out in three work packages:

- **WP1 Ontology Development and Compliance Validation** provided ontologies and tools to transform and compare them.
- **WP2 Semantic Container Management** developed the "semantic container" concept, and described the kind of infrastructure that would be needed to support it, particularly from a data distribution point of view.
- **WP3 Practical Experimentation of Semantic Technologies in SWIM** developed some use case scenarios showing how the semantic container approach could be used, and provided proof-of-concept implementations of this.

The role of **WP5 Evaluation Leading to Recommendations to Practitioners** was to provide technical support to the three core technical work packages, in particular providing assessments and recommendations concerning scalability issues for implementations, and approaches to modularisation of ontologies.

The role of **WP4: Stakeholder Awareness and Relevance** was project promotion, partially through involvement of stakeholders to gather their views. The work package provided guidelines on how governance process could be influenced by use of semantic technologies, as well as tutorials aimed at people wanting to experiment with technical results produced by the project.

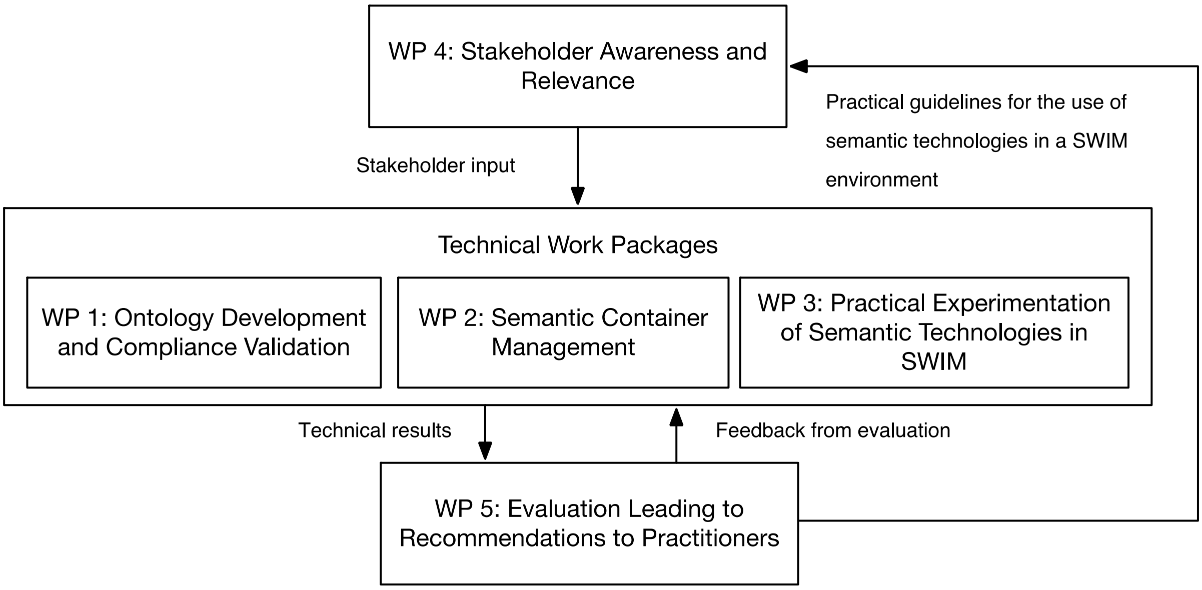


Figure 2: BEST work package structure (excluding Management)

2.4 Key Project Results

BEST produced a large number of tangible results. The sections which follow describe each main result in a simple tabular form. There is one table per result, describing the name of the result, a brief description of what it is, the benefits it can bring, and what "next steps" might be taken to further develop or use it.[1]

The tables below also indicate which deliverable is the one relevant for each result. Some project deliverables provide more than one of the items that we identify as project results, so you will notice that in some cases the same deliverable is referred to in more than one result summary table.

Full details of the results are available in project deliverables, available via the project website. In some cases, project deliverables have associated technical entities (software, ontologies etc); information on how to access these is provided on the project website alongside the relevant deliverable.

Because there are so many results, we have classified them by type/nature and organised them into separate sections as follows. We hope this makes it easier for you to find the types of results of most relevance to your interest. They are classified as follows:

2.4.1 New Concept developed in BEST: Semantic Containers

2.4.2 Prototypes demonstrating technical feasibility of Semantic Containers

2.4.3 Tools and Infrastructure developed for experimentation and potential use outside BEST

2.4.4 Ontologies developed in BEST for experimentation and possible re-use

2.4.5 Recommendations for Practitioners

2.4.6 Resources and Publications for Dissemination and facilitation of uptake of project results

[1] Regarding "Next steps", note that for some results / combinations of results, a more detailed strategy for possible directions for further work is provided in section 4.3.2.

2.4.1 New Concept developed in BEST: Semantic Containers

This section describes the results of work carried out in BEST to develop a completely new concept. While these results are "theoretical" in nature, parts of the work are concerned with ensuring practical applicability. Furthermore, results described in the following section demonstrate the practical potential of the new concept.

As mentioned in the introduction in section 2.1, BEST is about maximising the benefits of adopting the SWIM approach to information management. SWIM involves adoption of an information sharing approach "*where information producers do not need to know anything about who might use the information, and where information consumers can access information from different sources as they please*" [quote from section 2.1]. For this to be practical, support is needed for information consumers to be able to specify their information need, and for technical infrastructure to be able to locate the information that best matches this need. BEST work on *Semantic Containers* was motivated by this need.

Semantic Containers: The concept	
Description:	Set of techniques for ontology-based data description and discovery in a decentralised SWIM knowledge base.
Relevant Deliverable(s):	D2.1 Techniques for ontology-based data description and discovery in a decentralized SWIM knowledge base
Key benefits:	• Can be combined with SWIM services to associate meta-data with ATM information, and so: o Make it easier to find exactly the information required: o Enable automated distribution and replication of information (with caching), for increased availability and accessibility of information. • The faceted approach using existing semantic technologies and ontology modules (from D1.1) provides a very flexible and extensible mechanism to describe meta information.
Next steps:	In the short-term, the advantages of the proposed approach should be made known to stakeholders responsible for operationalisation of the SWIM service concept. (This report is itself a key part of that strategy). However, real progress with introducing the concept can only be achieved when SWIM services start to become operational on a wide scale: only then will it be possible to demonstrate the container concept in a real SWIM setting. But that is probably some years away. (Currently, only a very limited number of services are being implemented.) When that time comes, the next step will be to demonstrate the concept with some real operational services, and compare the effectiveness of information access with/without containers.

Semantic Containers: Infrastructure needed to distribute data	
Description:	For the Semantic Container concept to work in practice, it is necessary to provide infrastructure – a Sematic Container Management System – to arrange that containers are distributed and replicated at multiple locations in a network. This result describes how such infrastructure could be implemented effectively.
Relevant Deliverable(s):	D2.2 Ontology-based techniques for data distribution and consistency management in a SWIM environment
Key benefits:	Using the approach described in this result it will be possible to implement infrastructure where: • ATM information packaged into semantic containers with associated meta-data can be stored redundantly on different server nodes for increased availability. • The metadata facilitates information discovery and re-use in a distributed environment. • It is possible to configure things so that a given semantic container can derive information from other containers, consolidating information. • All of this can be done in a distributed environment where different services produce and update the source information.
Next steps:	The very first step is to provide an implementation of a Semantic Container Management System. A prototype was already produced in the project (described in section 2.4.2 below); it would need to be developed to the standards required in an operational environment. Beyond that, the next steps are the same as for the Semantic Container concept itself (see above).

2.4.2 Prototypes demonstrating technical feasibility of Semantic Containers

This section describes results produced in the project, including software implementations, to show the value of the new concept described in the previous section (Semantic Containers). The software developed in the project is intended only as proof-of-concept demonstrator, and has no direct role outside the project itself. However, parts of it could be refined and extended in future to form the basis for operational implementations of the Semantic Container concept.

In order to demonstrate the viability of the Semantic Container concept (see above), BEST implemented a prototype to illustrate how the concept could be implemented and integrated within a SWIM lifecycle. This is illustrated in Figure 3 below.

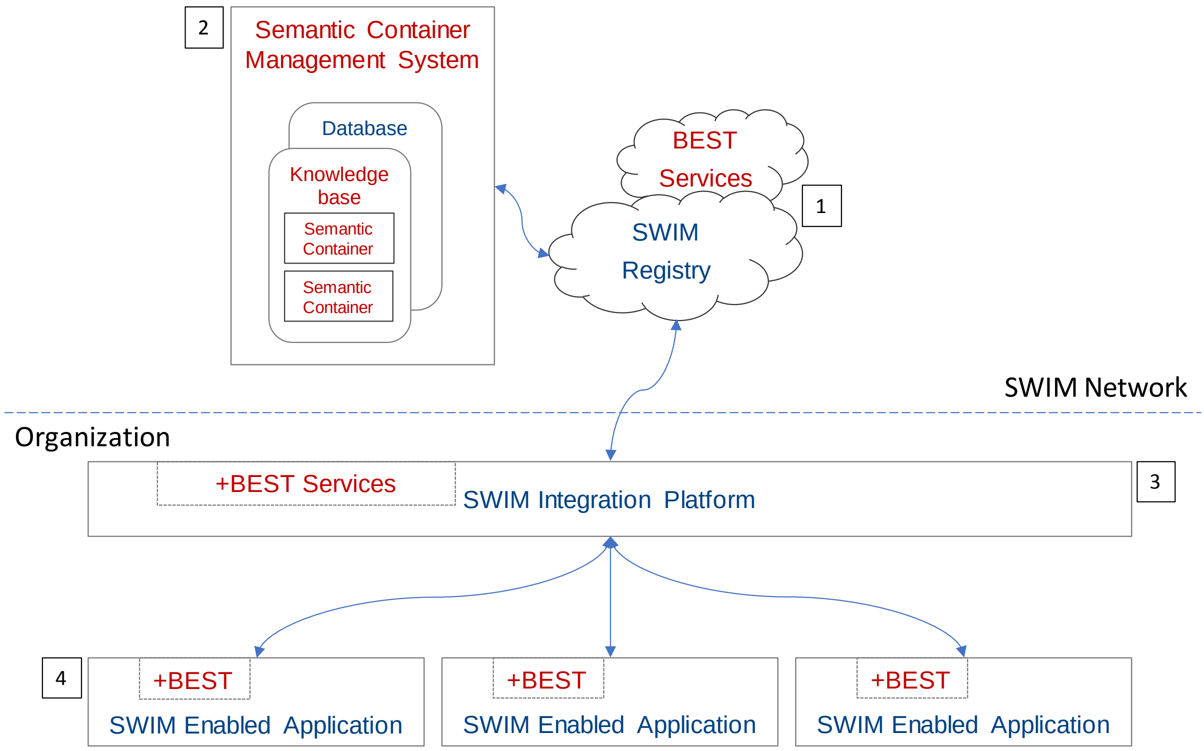


Figure 3. How BEST integrates with SWIM

The implementation is described in full D3.2, and summarised here. The Frequentis SWIM Registry (labelled “1” in the diagram) was integrated to provide not only information about SWIM services but also about Semantic Containers via SWIM. The BEST Semantic Container Management System (labelled “2” in the diagram) is used to define and create containers that are than visible through the SWIM registry. On an organizational level the Frequentis SWIM Integration Platform (labelled “3” in the diagram) is used to configure organization internal the SWIM information for the specific SWIM applications. Finally, the information is accessed by a SWIM application. For the BEST integration we used an existing SESAR prototype, namely the Integrated Digital Briefing (labelled “4” in the diagram) from WP13.2.2.

Use Case Scenarios	
Description:	A set of use case scenarios designed to illustrate the capabilities of semantic containers in a SWIM enabled environment. They are a pre-requisite for development of proof-of-concept applications (see next result).
Relevant Deliverable(s):	D3.1 Prototype Use Case Scenarios
Key benefits:	The scenarios provide a way to illustrate the advantages of the Semantic Contain approach, specifically: • Provide a comparative analysis of current information exchange approaches, information exchange with SWIM, and information exchange with SWIM complemented with the Semantic Containers. • Demonstrate how the Semantic Container approach handles different kinds of ATM information, such as aeronautical, meteorological and flight plan information.
Next steps:	The first step after definition of the scenarios was to use them as the basis for proof-of-concept applications (see below). That has already been done in the project. For the future, the scenarios should be extended to cover a wider set of use cases, illustrating real operational situations. As for the Semantic Container concept itself (see above) those steps can only be taken when SWIM services become operational on a wide scale.

Proof-of-concept Applications	
Description:	Proof-of-concept implementation of the Semantic Container concept in an operational setting, based on the Use Case Scenarios, and supporting information distribution and replication.
Relevant Deliverable(s):	D3.2 Prototype SWIM-enabled Applications
Key benefits:	• Practical demonstration in the form of two proof-of-concept prototypes showing: o How semantic containers are created and integrated with SWIM. o How the Semantic Container approach can extend the SWIM concept and add value to it by data discovery through semantic annotation and leveraging necessary benefits in SWIM networks. • A theoretical analysis showing several benefits with respect to - amongst others - end-user functionality and performance of implementing the Semantic Container approach.
Next steps:	Considering that as of today no SWIM service is operational (see [10]), we need to acknowledge that any service on top – like Semantic Containers – will require even more time before they become operational. Nevertheless, more and more SWIM services will become operational over time and it makes sense to already think now about addressing foreseeable bottlenecks that can be solved with Semantic Containers. In the longer term, some parts of the software developed in this application could be refined and extended to form the infrastructure needed to support the Semantic Container concept i.e. a Semantic Container Management System.

2.4.3 Tools and Infrastructure developed for experimentation and potential use outside BEST

The results described in this section were developed in BEST to allow research experimentation in order to address the research questions of the project. However, these results are already in a form suitable for use by stakeholders outside the project who might want to experiment with the same ideas for their own purposes.

Automated Ontology Engineering: Script-based transformation from AIRM/AIXM to OWL	
Description:	Technical work in BEST needed an ontology representation of AIRM – but it is defined entirely in UML. However, ontology engineering (i.e. producing ontologies from other models/transforming ontologies) is a process that typically requires a lot of manual effort and time. This result was produced to speed up this process: it consists of a set of transformation scripts that can automatically transform AIRM and AIXM to OWL. The transformation uses a combination of the transformation language XSLT and the UML to OWL mapping rules defined by OMG [7].
Relevant Deliverable(s):	D1.1 Experimental ontology modules formalising concept definition of ATM data
Key benefits:	• It is easy to produce OWL representations of AIRM and AIXM: it has already been done for the current versions of these models, and can be done again quickly and easily when these are updated in future. • Having OWL representations of these models allows experimentation with existing semantic technologies, and with new tools developed in BEST.
Next steps:	• *Script dissemination*: make scripts available to other researchers to use/extend (already done: information on website on how to access and use the scripts). • *Script evolution:* if new rules are defined for UML to OWL transformation, update the scripts to take these into account. • *Script re-runs* for new versions: When new version of AIRM and AIXM are developed, run the scripts again to produce new OWL representations that are consistent with the new versions.

AIRM Compliance Validator	
Description:	Proof-of-concept application that partially automates the task of verifying compliance between ontological representations of the ATM Information Reference Model (AIRM) and other ontologies (such as ones developed in the project).
Relevant Deliverable(s):	D1.2 AIRM Compliance Validator
Key benefits:	Compliance validation is a task that is essential if standard models are to be used in practice, with confidence that applications adhere to the standards. But the task involves huge amounts of checking, and current methods are labour-intensive and highly error-prone. The Compliance Validator demonstrates that it is feasible to automate the process (at least partially) so that: • Cost associated with compliance validation will be significantly lower; • Time spent on compliance validation will be considerably shorter; • Confidence in the results of validation assessments will be higher; • The probability that standard models will be widely adopted will increase.
Next steps:	• Make the tool available to other researchers, to test it /experiment with its application to other ontologies (already done: information on website on how to access and use the tool). • Contact NASA to use the tool as part of a process of matching AIRM with an ATM information model developed independently by them (already under way: the BEST team is already in touch with NASA and are currently – as of July 2018 – developing a manual mapping that will later be compared with an automatically produced mapping). • Apply the validator in other domains. • Develop operational versions of the validator, using the BEST proof-of-concept validator as a basis. *SEE ALSO:* Section on "Automated Compliance Verification" in section 4.3.2.

Tools for Ontology Modularisation	
Description:	Prototype tools to allow an ontology to be broken down into smaller modules, using different criteria for doing the modularisation.
Relevant Deliverable(s):	D5.2 Ontology Modularisation Guidelines Note: *Although the formal title of the deliverable refers only to "guidelines", the work done in creating the deliverable also developed the tool.*
Key benefits:	Large information models expressed as ontologies can be difficult to "manage" – from both the organisational/governance point of view and the processing point of view (tool efficiency/scalability issues). It can therefore be desirable to split ontologies into smaller, more manageable modules. But large ontologies often include complex interdependencies between parts, making it difficult and time-consuming to decide how to modularise. The modularisation tool demonstrates that it is feasible to automate the process so that: • It becomes feasible to experiment with different modularisation strategies, based on different parameters, without having to spend lots of time; • Modules can be created that can be subject to (almost) independent governance, with dependencies between modules clearly documented; • Modules can be created that can be used in processing tools without facing efficiency/scalability issues.
Next steps:	• Make the tool available to other researchers, to test it /experiment with its application to other ontologies (already done: information on website on how to access and use the tool). • Use the modularisation tool in co-operation with people involved in AIRM governance to try to identify candidate modules for future work. *SEE ALSO:* Section on "Automated Compliance Verification" in section 4.3.2.

2.4.4 Ontologies developed in BEST for experimentation and possible re-use

The results described in this section are all ontologies, expressed in OWL. They were produced using the tools described above. All are publicly available for experimentation and use – details of how to access them are available on the project website together with information about the relevant deliverable.

The AIRM OWL Ontology	
Description:	AIRM transformed from its UML representation to OWL, using BEST tools.
Relevant Deliverable(s):	D1.1 Experimental ontology modules formalising concept definition of ATM data
Key benefits:	• Becomes possible to apply semantic technologies (tools developed in BEST as well as other pre-existing tools).
Next steps:	• Update the ontology using the BEST transformation tools if and when the UML version gets updated.

Ontologies representing the AIXM and IWXXM exchange models	
Description:	Information exchange models AIXM and IWXMM transformed to an OWL representation, using BEST tools.
Relevant Deliverable(s):	D1.1 Experimental ontology modules formalising concept definition of ATM data
Key benefits:	• Becomes possible to apply semantic technologies (tools developed in BEST as well as other pre-existing tools). In particular: when used together with the AIRM ontology, it becomes possible to automate the process of checking compliance between exchange models and the AIRM.
Next steps:	• For each exchange model: update the ontology using the BEST transformation tools if and when the exchange model version gets updated.

Ontology Modules	
Description:	A variety of modules, derived from the AIRM using different criteria (broadly: some based on module size; some based on concepts selected by the user).
Relevant Deliverable(s):	D5.2 Ontology Modularisation Guidelines
Key benefits:	There is no direct benefit from specific modules. The benefit is at higher level: the ability to experiment with different modularisation strategies to rapidly generate modules based on different strategies.
Next steps:	*See remarks above for result "Tools for Ontology Modularisation".*

2.4.5 Recommendations for Practitioners

The results in this section are documents that provide guidance to stakeholders, based on experimentation, tools and experiences gained in BEST. They do not include any software or other technical artefacts.

Stakeholder View	
Description:	Describes the views of key ATM stakeholders about the ideas and concrete results from BEST – some from early in the project when ideas were immature, and some from nearer the end of the project when results were mature.
Relevant Deliverable(s):	D4.1 The Stakeholder View
Key benefits:	• Provides validation of acceptance by ATM stakeholders of the overall idea that semantic technologies can be beneficial to ATM information management. • Provides specific feedback (positive and negative) about details of the BEST approach; this can be useful for guiding future work in the area. • Provides ideas about ways in which the scope of the work done in BEST could be extended, both within the ATM domain and to other domains.
Next steps:	In any future work building on BEST: • Maintain contact with some or all stakeholders who are members of the BEST Reference Group and extend it to cover the views of others as well. • Use the feedback already received to guide the direction of future work.

Modularisation Guidelines	
Description:	Advice about different approaches to modularisation of ontologies, based on the possibilities that re opened up by the modularisation tool developed in BEST.
Relevant Deliverable(s):	D5.2 Ontology Modularisation Guidelines
Key benefits:	• Stakeholders who might want to consider splitting a model into small modules – for whatever reason – can make good decisions about how best to do so.
Next steps:	• When stakeholders use the modularisation tool and guidelines: use their experiences and observations to update the guidelines as needed. *SEE ALSO:* Section on “Automated Compliance Verification” in section 4.3.2.

Governance Guidelines	
Description:	Advice about the feasibility of using semantic technologies in SWIM Governance, and specific advice about how they could be used. The possibilities opened up by the automated compliance testing and modularisation implemented in BEST receive particular attention.
Relevant Deliverable(s):	D4.3 Governance Recommendations for the use of Semantic Technologies in SWIM.

Key benefits:	• People from SWIM Governance can become well-informed with little effort about the potential offered by semantic technologies for governance of different entities that are needed for effective implementation of SWIM.
	• If semantic technologies are adopted in SWIM Governance:
	  o Governance can become more effective if applied to smaller modules (produced using partially automated methods): smaller, tighter, more expert teams can make better quality decisions more rapidly.
	  o The task of carrying out compliance validation can be carried out more rapidly and more cheaply, with greater confidence in the results. Since compliance validation can be regarded as part of “governance”, this implies more effective governance.
	Note: While modularisation can lead to overall more effective governance, it does not mean the issue of taking care of inter-dependencies goes way completely: some governance approach will still be needed for this.

Next steps:	• In the short-term, make the relevant results of BEST available to the SWIM Governance project. [This has already been done]. • Arrange a meeting with the SWIM Governance team to present the recommendations and enter into a dialogue about how they might influence approaches to governance in the short, medium and long term. *SEE ALSO:* Section on “Automated Compliance Verification” in section 4.3.2.

Scalability Guidelines	
Description:	Describes an approach to assessing scalability aspects of using the Semantic Container approach developed in BEST, and the results of experiments carried out to measure and assess scalability on some specific cases. Based on these experiments and other work in BEST, a set of seven recommendations are provided advising on measures to take to promote scalable solutions when using semantic technologies.
Relevant Deliverable(s):	D5.1 Scalability Guidelines for Semantic SWIM-based Applications
Key benefits:	• Developers of future implementations are more likely to be able to develop solutions with good scalability characteristics. • Scalability assessment of future implementations can be carried out in systematic and reliable way (using the approach developed in BEST).
Next steps:	The work done to produce these guidelines was based on a rather limited set of measurements and test case. To produce more robust and widely applicable recommendations, future steps would include: • Carry out more experiments using different timescale constrains, more closely tuned to likely requirements in different application scenarios. • Extend the scope to cover different reasoning algorithms. • Extend the scope to cover different types of ontology expressivity.

2.4.6 Resources and Publications for Dissemination and facilitation of uptake of project results

The results in this section are about making the knowledge gained and artefacts produced in the other results more easily accessible to the wider ATM and research community.

Tutorial for SW Developers	
Description:	BEST produced a variety of software artefacts that can be of interest outside the project. All of these are available for download (details on the project website). This "tutorial" provides hints and advice for anyone wishing to use the software.
Relevant Deliverable(s):	D4.4 Tutorial for SW Developers
Key benefits:	• The probability that people outside BEST will be able to successfully use the software for their own purposes is increased. This in turn contributes to the results being more widely used.
Next steps:	The tutorial is good enough for anyone wanting to use the existing software – we do not see the need for any future steps to improve it. However, if any of the software produced becomes improved or extended (or even, ultimately, commercialised) it will be necessary to provide updated "tutorials" or other documentation to promote successful and widespread adoption.

The project also produced a set of publications, and presented the project at various conferences etc. These are also project results and belong in this section of the report. However, the standard template for this type of report requires that they be reported in a separate section – please refer to section 5.2.

2.5 Technical Deliverables

The table below shows all the deliverables produced in BEST. All public deliverables are available on the project website, accompanied by extended summaries of the content and (where relevant) indications of how software, ontologies and other technical resources can be accessed. All of these can be accessed with a single click from the following page:

http://project-best.eu/publications.html

In the event that the website is for any reason unavailable, the project's deliverables will be available via the European Commission's CORDIS site, at:

https://cordis.europa.eu/project/rcn/204166_en.html

Deliv. No.	Title	Description	Diss. Level	Delivery Date
D1.1	Experimental ontology modules formalising concept definition of ATM data (R2)	Ontologies for content definition in decentralized knowledge base (provides ontologies to be used for describing the content in semantic data containers / decentralized knowledge bases.	Public	06 Jun 2017
D1.2	AIRM Compliance Validator (R4)	Prototype software application that will identify correspondences among an AIRM Ontology developed as a representation of the AIRM Information Models and the ontology modules developed in BEST.	Public	26 Apr 2018
D2.1	Techniques for ontology-based data description and discovery in a decentralized SWIM knowledge base (R3)	This deliverable comprises - a method for the semantic description of data products building on ontologies from WP1 - techniques for discovering most relevant data products for a given information need.	Public	09 Mar 2018
D2.2	Ontology-based techniques for data distribution and consitency management in a SWIM environment (R5)	This deliverable comprises an ontology-based language for describing data distribution, including data lineage and freshness requirements.	Public	18 May 2018
D3.1	Prototype Use Case Scenarios	This deliverable is provided as a report that includes a set of use case scenarios that will guide the development of the Prototype SWIM-enabled Applications.	Public	23 Mar 2018
D3.2	Prototype SWIM-enabled applications (R1)	Provides a set of proof-ofconcept prototypes that will demonstrate the potential of the semantic-based approach used in BEST. The prototypes will implement the ontological structures developed in WP 1 and the decentralised SWIM Data and Knowledge Base from WP 2.	Public	22 May 2018
D4.1	The Stakeholder View	Report describing the views of key stakeholders about the kind of support they expect semantic technologies could provide.	Public	30 May 2018
D4.3	Governance recommendations for the use of semantic technologies in SWIM (R9)	Describes an overall approach to governance that deals with the emergence and evolution of semantic technologies in ATM. An emphasis will be put on how ontologies can co-exist and co-evolve and how to manage their dependencies with AIRM and other relevant information exchange models and standards.	Public	22 May 2018
D4.4	Tutorial for Software Developers (R6)	Describes how semantic technologies can be implemented in a SWIM environment. It will include lessons learned from the developments in BEST and be targeted towards software developers of ATM applications.	Public	30 May 2018
D4.5	Dissemination and project promotion report	Describes all dissemination and project promotion activities that took place during the project, together with an assessment of their possible impact.	Public	24 May 2018
D5.1	Scalability Guidelines for Semantic SWIM-based Applications (R8)	Set of guidelines on how applications using semantic technology can be applied in the ATM domain with good scalability characteristics.	Public	28 Apr 2018
D5.2	Ontology Modularisation Guidelines for SWIM (R7)	Provides a set of guidelines on how different ontology modules can be reconciled into a consistent and coherent "network" of ontology modules.	Public	09 March 2018
D6.3	Project Results Final Report	Produced in accordance with the requirements defined in "SESAR Project Execution Guidelines for SESAR 2020 Exploratory Research", summarising project results in a form suitable for publication.	Public	21 August 2018

Table 1: Technical Project Deliverables

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

The main objective of the BEST project is to determine how semantic technologies can maximise the benefits of adopting SWIM for improved information management. Improving information management processes will also bring operational improvement in areas relying on accurate, reliable, and easily accessible information. As such there are a number of operational improvement steps that indirectly can be affected by the contributions from the BEST project, although only one OI step is directly relevant and included in Table 2.

Table 2: Project Maturity

Code	Name	Project contribution	Maturity at project start	Maturity at project end
IS-0204 OI/EN code	Facilitated Aeronautical Data Exchanges through Digitalised/Electronic Information	The concept of Semantic Containers proposes an ontology-based information sharing approach that complements the service-oriented architecture of SWIM.	TRL 0	TRL 1

3.2 Maturity Assessment

ID	Criteria	Satisfaction	Rationale – Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Achieved	The challenge addressed by the project is identified as a set of key research questions – as described in section 2.2. These can be summarised at a high-level as addressing two key challenge areas: • *The challenge of improving information exchange and thereby avoiding information overload and contributing to achieve common situational awareness:* This is addressed in deliverables D2.1 (Techniques for ontology-based data description and discovery in a decentralised SWIM knowledge base) and D2.2 (Ontology-based techniques for data distribution and consistency management in a SWIM environment). • *The need for guidelines and tools for supporting the governance process*: This is addressed in deliverables D1.2 (Compliance Validator), D4.3 (Governance Recommendations) and D5.2 (Modularisation Guidelines).
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	Not achieved	Such a quantitative analysis was not planned and was therefore not carried out.

TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others."	Achieved	Potential weaknesses and/or areas where further work is required, are identified in individual project deliverables, and also in the "Next steps" entries in the tables summarising project results in section 2.4 of the project "Final Report" (D6.3). Some specific constraints for future work have been identified: • Lack of operational SWIM services/data means that industrial validation can only happen when these become available, and we do not currently know when that is likely to be. • Currently difficult to evaluate scalability implications of the semantic container concept.

TRL-1.4	Has the concept/technology under research been defined, described, analysed and reported?	Achieved	The principles of the semantic container concept are described in deliverables D2.1 and D2.2. D3.1 defines a set of use cases for which the semantic container concept could be applied, while D3.2 explains how the semantic containers are implemented in the use cases. Together these deliverables clearly define, describe, and analyse how the semantic container concept can contribute to enhanced aeronautical information exchange. The ontological infrastructure used in the ontology-based data description in the semantic container concept is developed in D1.1 and D5.2 (ontology modularisation). Automated compliance assessment is described in D1.2, where a prototype application (AIRM Compliance Validator) is thoroughly evaluated in datasets consisting of AIRM and the exchange models AIXM and IWXXM. Together with D5.2, D1.2 provides input to the formulation of governance recommendations in D4.3. All software developed in the project, as well as how it can be used, is described in D4.4 which provides a tutorial for software developers.

TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Achieved	Yes, the semantic container concept directly contributes to facilitating aeronautical data exchange (IS-0204). Improved aeronautical data exchange and improved semantic interoperability will in turn have an indirect positive effect on most other operational improvement steps.

TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	Achieved, at the proof-of-concept level.	There are several innovations in BEST: 1. With the AIRM Compliance Validator BEST has made a contribution with respect to reduce the manual effort required for assuring compliance with the AIRM as well as the more general goal to support semantic interoperability within ATM. A proof-of-concept application has been developed and all source code for this application is made available so that others can extend it to a higher TRL level application. 2. The semantic container concept is an innovation that complements existing SWIM infrastructure and enhances aeronautical information exchange. Proof-of-concept applications are developed in D3.2 demonstrating that the concept can be technically implemented when SWIM services and data are operational. However, full validation of benefits related to data freshness, provenance and quality can only happen when operational SWIM services become operational. 3. The governance recommendations combined with modularisation principles and tools can help resolve some of the issues related to current governance regimes. Our ambition is that these recommendations and tools can be a useful input to the SWIM Governance project.

TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	Not Applicable	
TRL-1.8	Have the potential strengths and benefits been identified? Have the potential limitations and disbenefits been identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	Achieved	The benefits of all results from the project are described in detail in the tables in section 2.4 of the Final Report.
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	Achieved	Yes, the project has produced 4 scientific publications concerning the semantic container concept, 1 scientific publication about the scalability guidelines associated with semantic containers, and 1 scientific publication about the AIRM Compliance Validator. Additional information about the publications from BEST can be found in D4.5 and in section 5.2 of the Final Report.
TRL-1.10	Have the research hypothesis been formulated and documented?	Achieved	Yes, all research questions formulated in the DoA are addressed by the relevant deliverables.
TRL-1.11	Is there further scientific research possible and necessary in the future?	Achieved	Yes, since BEST is an exploratory research project at TRL 1 level, all developments could potentially be extended to higher TRL levels and be subject to larger-scale development and industry testing. We have also identified some areas where some of the results from BEST can be used to address other research challenges relevant to ATM (see chapter 4.3).

TRL-1.12	Are stakeholders interested about the technology (customer, funding source, etc.)?	Partially Achieved	A survey performed in the initial part of the project showed that the majority of respondents (78 %) were positive about the usefulness of BEST despite the fact that many of them were unfamiliar with semantic technologies. During interactive reference group meetings the main feedback was that: the semantic container concept was appealing; the transformation tools and the AIRM Compliance Validator were considered "good news" as they demonstrate feasibility of applying semantic technologies for real cases; the possibility of modularising information models triggered some interest from a governance point of view; and that BEST does a good job of showing the capabilities of semantic technologies in ATM, forming a good basis for future work.

4 Conclusion and Lessons Learned

4.1 Conclusions

4.1.1 Overall Conclusions

When the project was nearing completion, meetings were arranged with key ATM stakeholders (the BEST "Reference Group") and their opinions sought about the usefulness (or otherwise) of project achievements. Some key points from their feedback are listed below; we consider that they provide a summary of the main conclusions about the work done:

- It is clear that semantic technologies can be applied to the domain of ATM information management and bring benefits.
- The semantic containers concept can help strengthen the benefits of SWIM services.
- Some of the concepts related to "semantic technologies" and mechanisms to apply them can be difficult to understand for people without specialist knowledge (and many in the ATM domain lack such knowledge). BUT: it is possible to communicate the BEST approach to a willing audience in such a way that they can see the main benefits without having to understand all the technical details. It is therefore feasible to apply these concepts in this domain.
- Meta-data related to data *quality* [one of the things supported by semantic containers] can be particularly useful – there has been a tendency in ATM to focus too much on data *source*.
- Automated compliance checking can be useful not only to demonstrate compliance but – by providing automatically generated compliance *reports* - help identify areas where changes are needed to bring about compliance.
- The success of SWIM is not just about technology, it is also about organisational issues and how decisions are made regarding "standardisation". BEST contributions to governance could be useful here – especially through automated modularisation enabling use of smaller modules and change control boards with specific domain expertise.
- Modularisation brings benefits – but does not mean that inter-dependencies will not exist. Thus: mechanisms and procedures to deal with that must be carefully designed.
- BEST can help address the issue of "information overload", which has sometimes been presented as an objection to adoption of SWIM; it can therefore contribute to promoting adoption of SWIM.
- Work about automation of matching and filtering of information could benefit from use of artificial intelligence techniques, and work on this should be considered for the future.
- The work done in BEST was only about *ATM* information. It would be beneficial to extend the scope and approach to include other kinds of information (e.g. business information, cost of data), and indeed to use to deal with sharing information with other related domains.

4.1.2 Specific Conclusions: Answers to Research Questions

BEST set out to answer a set of research questions. So a key set of conclusions from the project must be the answers to these questions.

What kinds of ATM data / metadata can be handled effectively using semantic technologies, enabling composition and filtering of data, and so producing innovative ATM applications?

BEST was able to use semantic technologies to deal with all kinds of ATM information defined in the AIRM, and a wide variety of types of meta-data (through work on semantic containers). No indications of restrictions or limitations were noted; it seems safe to conclude that ontologies are well-suited for all kinds of ATM information and meta data.

How can we ensure that ATM solutions developed using semantic technologies have scalability characteristics that allow them to be used successfully even when data volumes, complexity and load increase?

BEST was able to assess this for some specific cases, and make some recommendations related to these. However, it was not possible to answer the question in the most general case, so scalability remains an issue that needs to be considered further.

How can ontology matching be used to automatically identify overlaps between ontologies and ensure compatibility among them?

Work in the project demonstrated convincingly that it is feasible to provide tool support for this task that automates much of the work, reducing the need for manual work substantially. However, it is not possible to automate the process completely.

How can metadata expressed in ontologies be used to optimise SWIM data distribution (e.g. to influence replication strategies)?

Detailed ideas for how this could be done were developed in project deliverable D2.2 and demonstrated successfully in proof-of-concept applications developed in D3.2.

In order to (ultimately) provide ontology-based modelling of the full breadth of all ATM information, how can a practical modular approach be designed that balances factors such as scope, scale, overlap and data distribution?

BEST showed that it is feasible to automate transformation of models described in other ways (e.g. AIRM expressed in UML) to be expressed as an ontology. It also showed how a large ontology (such as the one for the AIRM) can be automatically split into smaller modules, using different selection criteria. Data distribution aspects were successfully described in D2.2 and D3.2.

What processes and tools should be used to govern evolution of ontologies, and to ensure that they comply with higher-level standard models such as AIRM?

BEST showed that it is feasible to split a large model such as AIRM into smaller modules using mostly automatic means, and that is furthermore feasible to automatically check that modules (or indeed other ontologies) are consistent with the large module. There are clear advantages for governance: simplified and more rapid decision-making and change control board membership with more focused domain knowledge. BUT: inter-dependencies between modules will always be present, and procedures will be needed for dealing with these.

4.2 Technical Lessons Learned

4.2.1 Lessons learned from ontology development

Our experience from the automated transformation of OWL ontologies from UML models is mostly positive. It saves a lot of manual effort as ontology engineering is a very laborious task. Developing the transformation scripts required some effort, but the reward of having automatically generated OWL models made the process much more efficient than if the ontologies were to be developed by hand. The fact that the UML entities along with their definitions were directly copied over the OWL representation avoided manual mistakes (for example typos is OWL entity names and definitions).

The mapping rules specified by OMG (Object Management Group 2014) were a great help in writing the transformation code and contributed to the validity of the resulting OWL models.

One could say that since the resulting OWL models are syntactical copies of the UML models, without much of the semantics often represented in OWL ontologies. However, such semantics can be added manually to the OWL models after the transformation if needed.

4.2.2 Lessons learned from compliance verification

From the experiments of the AIRM Compliance Validator we learned that quite simple ontology matching techniques can automatically discover equivalence relations pretty well, and when combining techniques this leads to an even better result.

It is more challenging to automatically identify other semantic relations, such as subclass relations. One reason for this is that “other semantic relations” is not well defined, such that identifying the concrete patterns from which matching techniques can be developed is problematic. In several of the experiments, some of the techniques applied obtained quite good recall (they identified several of the mappings that were expected), however since they also identified a large number of false mappings, their precision, and consequently the overall performance was quite low.

4.2.3 Lessons learned from development of techniques for semantic container management

Based on the functional requirements and backed by experimental evaluation, we conclude that semantic web technologies are in general well-suited for realizing the semantic container approach. With respect to technology choice, a mix of semantic web technologies seems appropriate. Different aspects of semantic container management and discovery require different degrees of expressiveness and, therefore, must be realized with different technologies. In general, technology choice is always a trade-off between expressiveness, scalability as well as development and maintenance effort. For example, while RDF places no restrictions on expressiveness, the corresponding reasoning tasks must be solved by custom-built software which also results in potentially higher maintenance effort. OWL, on the other hand, trades off expressiveness for general decidability and scalability but off-the-shelf reasoners then support many tasks that would otherwise have to be custom-built.

The AIRM ontology developed in WP1 is a well-suited foundation for defining facet-specific ontologies which are in turn used for defining membership conditions of semantic containers. Importing only relevant AIRM ontology modules instead of importing the monolithic AIRM ontology not only better supports knowledge organization but also helps to speed up semantic reasoning. Modularization of the ontologies for semantic container description into orthogonal facet-specific ontologies allows to split the reasoning process into tractable subtasks. Specialisation hierarchies are derived independently for each facet and are then combined for organizing semantic containers in derived specialisation hierarchies and for matching information needs with available semantic containers. Additionally, this kind of modularization facilitates the use of different reasoning techniques for different modules, e.g., for deriving a specialisation hierarchy of a spatial facet it is more efficient to use a special-purpose reasoner instead of a general purpose OWL reasoner.

4.2.4 Lessons learned from use case analysis and prototype development

Considering that as of today no SWIM service is operational (see [10]), we need to acknowledge that any service on top – like Semantic Containers – will require even more time before they become operational. Nevertheless, more and more SWIM services will become operational over time and it makes sense to already think now about addressing foreseeable bottlenecks that can be solved with Semantic Containers.

It has been shown in a proof-of-concept scenario that Semantic Containers can extend the SWIM concept and add value to it by data discovery through semantic annotation and leverage necessary benefits in SWIM networks. Semantic Containers overcome the problem of stakeholders to query different information providers. A Semantic Container holds all required information for specific information need (e.g., flight from A to B, or service deliver at an airport) and contains data from a single data provider or from multiple data providers. Stakeholders do not have to find services which suit them but request a container with defined data quality (e.g., freshness, locality, and/or aircraft type) and semantic technology allows automatic identification of the best suited container in the available pool.

The integration of the Semantic Container concept into an existing SWIM application showed that it can be used without any changes and only little integration is necessary to visualize the add-value provided by the Semantic Containers.

4.2.5 Lessons learned from interaction with stakeholders in the domain

The main lesson learned from the interaction with the stakeholders is that many of the technical concepts in BEST can be difficult to comprehend for those unfamiliar with semantic technologies. Consequently, it is important to carefully choose presentation form and wording when interacting with industry stakeholders in order to ensure their understanding and getting valuable input. Use of real life examples and concrete use case scenarios when explaining technical concepts in BEST helped interaction with stakeholders and led to good discussions and useful feedback.

4.2.6 Lessons learned from governance recommendations

These are best expressed by summarising some of the key governance recommendations themselves:

Recommendations about how to decide whether to use semantic technologies in governance

- Be sure to adopt a clear definition of exactly what you mean by "Governance" and "compliance assessment".
- Time and effort required to carry out compliance assessment may be of crucial importance in bringing about widespread uptake of standards/models.
- For the specific governance role in which you are involved, systematically consider each of the "Issues" listed in section 3.2 (GI-01 to GI-05) of project deliverable D4.3
- When designing the membership structure of a CCB (Change Control Board), make sure that: (a) It provides balanced representation of all relevant stakeholder roles; (b) It contains people with appropriate detailed knowledge of technical issues related to the information model being governed; (c) Its size is not so large as to be cumbersome for practical day-to-day operation.
- If you want to split a model into separate modules, be aware that this can be a large and complex job, and that it may not be feasible without some kind of tool support.
- If you are considering using semantic technologies, be aware that this implies that users of models, and people involved in their governance, need some understanding of the idea of "ontologies" and the languages used to express them.

Recommendations for use of semantic technologies

- AIRM should remain as a single reference, expressed in UML.
- If semantic technologies create an ontology-based description of the AIRM, the AIRM community (or CCB) should provide some "official" approval of it.
- If semantic technologies (produced by BEST or some other source) are used to create a set of ontology modules of domain-specific subsets of AIRM, the AIRM community (or CCB) should provide some "official" approval of these, stating that they are consistent with the AIRM and provide full coverage of it.
- Even if "official" modules are defined, people should feel free to develop other "personalised" modules for specialist purposes.
- Any modules derived from the AIRM should be checked for correctness with respect to the AIRM.
- Any deficiencies observed in the single reference AIRM in UML can be addressed using existing AIRM governance mechanisms (CCB).
- Mechanism needed whereby changes to the reference AIRM trigger updates to relevant derived modules.
- Governance procedures should take account of the fact that the AIRM is used to derive XML schemas, exchange models etc., not just ontology modules.
- Information Exchange models must carefully ensure that their semantics are closely aligned with AIRM, to prevent semantic interoperability barriers.

4.2.7 Lessons learned from scalability analysis and modularisation techniques

A thorough scalability analysis requires substantial effort and a realistic as well as sufficiently mature environment in which experimentation can be conducted. The semantic container approach as proposed in the context of this exploratory research project is not yet mature enough to make definitive scalability guidelines. Based on this fact, D5.2 developed a framework containing an initial set of guidelines that can be extended upon in the future based on additional scalability analyses.

4.2.8 Lessons learned from modularisation techniques

The ontology modularisation approach we adopted was ontology module extraction using a technique called locality-based module extraction. The benefit of this approach over an alternative approach, ontology partitioning, is that the modules can be extracted on the basis of a topic-based query (a.k.a. seed signature). For example, one could specify that a module that contains all entities related to "Aircraft" should be extracted from the AIRM ontology. This approach also ensures local completeness of the resulting modules, contrary to partitioning-based approaches (e.g. creating modules based on the desirable number of classes in the extracted modules). Such an approach was appropriate for the purposes of modularisation in BEST, both from an application development and governance perspective, where it was important that the modules were organised according to topic (e.g. meteorology) rather than purely structural criteria such as size or number of hierarchical levels (as the ontology partitioning approach).

In order to support the formulation of guidelines for modularisation, we developed a set of software tools, both for extracting modules, for validating the results, and for managing dependencies between interrelated modules. The software was developed in java, with good support from the OWL API [6], a java library targeted for OWL ontology development.

4.3 Recommendations for future R&D activities (Next steps)

4.3.1 Overall Strategy and Timescales

BEST is a TRL[2] 1, Exploratory Research project. The SESAR definition of TRL 1 emphasises things like "curiosity-driven research". "unknown research areas" and "encourage scientists to develop innovative ideas and concepts". Given this context, it would not normally be expected that a TRL 1 project would develop technological results intended for commercialisation or inclusion in operational services. BEST *did* produce technical results (software and ontologies). Some of these are suitable for direct use by other researchers, while others are primarily to demonstrate technical feasibility. It could be that some of these may – one day – evolve to become commercial offerings. But that is not something to be expected in the near future.

We take this context into account in presenting ideas on future R&D based on BEST: we must do *both* of the following:

1. **Propose steps that encourage further research following directly from the work of the project.** A natural way to do this would be in the context of TRL 2 projects that would further develop ideas and technologies and validate more rigorously in specific application area(s) or operational scenarios. Ideas about this are described in section 4.3.2 below.
2. **Consider the longer-term and wider picture.** This involves looking to the longer-term and broadening the scope of how the results could be applied. Doing so was one of the recurring recommendations from the BEST Reference Group. Ideas about this are described in section 4.3.3 below.

[2] TRL stands for "Technology Readiness Level". It a nine-point scale (1-9) describing the maturity of a technical concept, with TRL 1 corresponding to a new, emerging concept or idea, and TRL 9 corresponding to something that is close to becoming a deployed product or service.

The "Expected Impact" section of the Grant Agreement predicted the expected impact of the project in the short-, medium- and long term. The table below summarises these expected impacts, adding some more detail and linking to timescales for steps need to achieve the impacts.

Timescale for impact *[from Grant Agreement]*	Nature of the expected Impact [from Grant Agreement]	Timescale[3] for activities needed to bring about impact
Short-term During project/within about 1 year of project completion	Help set the agenda for future work.	This section of this report already achieves this. Work in the next 6-18 months can advance this further.
	Contribute to overall process for maturing the technical concepts that were the subject of the proposal.	Detailed steps needed are defined below, in section 4.3.2. New projects could commence within 6-24 months. Expected duration would be 12-24 months.
Medium-term Within about 1-3 years of project completion	Stakeholders should be made aware of potential of semantic technologies	This was partly achieved during the project itself, through work with the "Reference Group". The momentum achieved with that should be maintained, to gather more detailed requirements, and to validate new ideas and tools as they emerge. While impact may not be for several years, some of the steps needed to bring it about can start earlier (within about 6-12 months of project completion) and may take 12-24 months. The medium-term impact can go beyond just being "made aware" and possibly include some actual adoption of semantic technologies – particularly for compliance assessment and modularisation.

[3] Timescales shown with respect to final completion of the project.

Timescale for impact *[from Grant Agreement]*	**Nature of the expected Impact [from Grant Agreement]**	**Timescale[3] for activities needed to bring about impact**
Long-term 4 or more - maybe *many* more – years after project completion	Improvements in: • Quality of data delivery • Consistency management Reductions in: • Information overload	These more ambitious impacts would mostly depend on work on semantic containers. That can only have major impact once SWIM services are operational, and that is not likely before about 2024. It is unlikely that detailed technical work on this could start before about 2-3 years from project completion.
	Improvements in: • Overall air safety Reductions in: • Pollution and noise	These expected impacts are of general/indirect nature, and not linked to specific research activities or timescales.

Readers of this report who might like to be involved in future research activities are strongly encouraged to contact the project coordinator of BEST to discuss ideas. An informal chat on the phone may be enough to generate fruitful future co-operation! Contact details:

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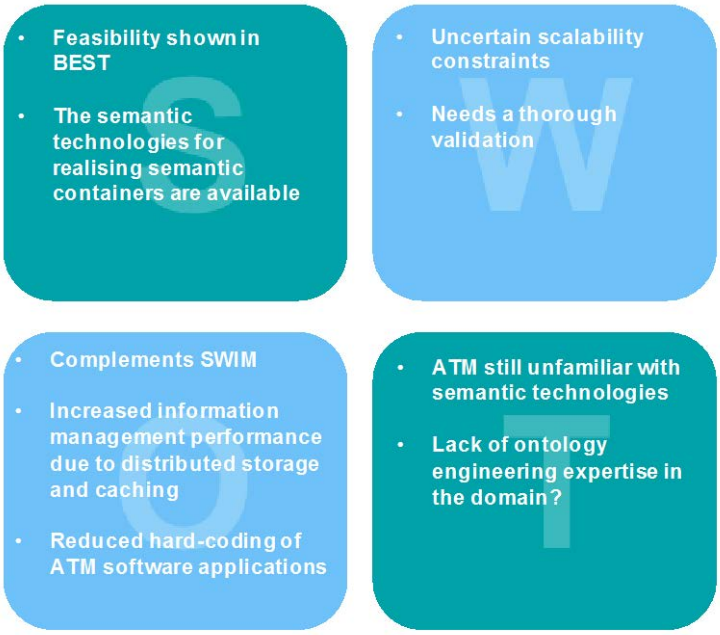
4.3.2 R&D to develop and adopt specific BEST results

We have identified the following BEST results as the ones where there is greatest potential for R&D that can start soon:

- Semantic Container Management System (including ontology development within ATM)
- Automated Compliance Verification
- Modularisation of information models (understandability/manageability of models - governance)

Each of the above can be further developed independently (e.g. in separate, smaller projects) but could also be developed in a combined project with wider scope. We have carried out a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) for each of these results, and present these below together with ideas about how future research might proceed.

Semantic Container Management System (including ontology development within ATM)



Ideas for new research directions building on work done in BEST:

1. Increase acceptance and understanding of semantic technologies in the ATM information management community.
2. Technical refinement: further develop the “ATM Information Cubes” concept proposed in deliverable D2.2. (It facilities generation of information summaries, to avoid “information overload” for users).
3. Investigate how trust in such a decentralised semantic container management system, e.g. using cryptographic protocols (e.g. blockchain protocols) could be provided.

4. Provide a robust semantic container management system (based on the proof-of-concept developed in BEST).
5. Validate the practicality of using semantic containers with operational SWIM services – including a wider range of scenarios, data from airlines, airports and ANSP.
6. Propose practical ways to integrate the container concept with the SWIM registry.

Potential Obstacles:

1. Lack of acceptance/understanding of semantic technologies in the ATM community.
2. Information published on the SESAR eATM portal [8], [9] indicates that deployment of SWIM services is not scheduled until 2024 or even later. This means that validation of integration with SWIM services cannot be carried out any time soon.

Timescale:

Step 1 has already started in the form of BEST publications and presentations, the BEST Reference Group and this report. But this work to some extent involves changing “attitudes”, and can take years to achieve.

Steps 2 and 3 could start within the next 12 months, provided that some suitable support mechanism can be found. We estimate that the work would take 12-18 months to achieve.

Steps 4-6 cannot start until closer to the time that operational SWIM services are active (i.e. from around 2024). It could take some years to complete.

Possible mechanisms to support/fund further work:

Steps 2 and 3 could possibly be funded as catalyst projects under the ENGAGE project (offering up to 60K euros for extending project results). Alternatively, they could be part of a TRL2 exploratory research project. However, they are probably not sufficiently wide in scope to constitute an entire project.

Step 4 would require product-quality software development work, which would likely be funded using internal resources of an industrial company.

Steps 5 and 6 could be funded as part of SESAR 2020 (or some follow-up to that).

Stakeholders:

- All actors involved in preparations for operational adoption of SWIM.
- Companies involved in the development of future SWIM services.
- Companies involved in producing technical infrastructure in support of SWIM.
- All actors involved in ATM information management.

Automated Compliance Verification

Ideas for new research directions building on work done in BEST:

1. Improve the coverage and precision of techniques used when evaluating possible semantic matches.
2. Include attributes of classes in the matching process.
3. Widen the applicability of the techniques by covering formats other than OWL (e.g. XSD models, UML models).
4. Identify any performance bottlenecks and scalability issues in the tool and refine the implementation to overcome these.
5. Define a clear *process* for carrying out compliance test with the support of automated tools, providing recommendations on how best to combine manual assessment with automated support. Should be based on case studies of full-scale assessments/comparisons.
6. In support of the previous step: improve the tool's GUI (e.g. to visualize alignments) to support the combined automatic/manual approach.
7. Develop ontologies for more information models, and use approaches developed in other steps to test alignment with AIRM. (A possible candidate is FIXM).

Potential Obstacles:

The only obstacle we perceive at the moment is that automated techniques may experience performance or scalability issues if using large and complex ontologies. It is therefore important that step 4 receive sufficient attention.

Timescale:

All of the above steps could in principle start as soon as some support mechanism can be found. It would be advisable for step 4 to be carried out in parallel with steps 1-3. We estimate that significant progress could be made with 12-18 months of work starting.

With respect to step 5, consortium members have already (immediately on completion of BEST) started work with NASA to produce a mapping between the ontology representation of AIRM and an ATM ontology developed independently by ATM. Initial work [as of July 2018] has been on developing a manual mapping; the next step planned is to include automated tool support from BEST in the process. All BEST partners (with the exception of SLOT) are involved in this work, and are currently financing the work from internal resources. There is enthusiasm to continue this work in the longer term.

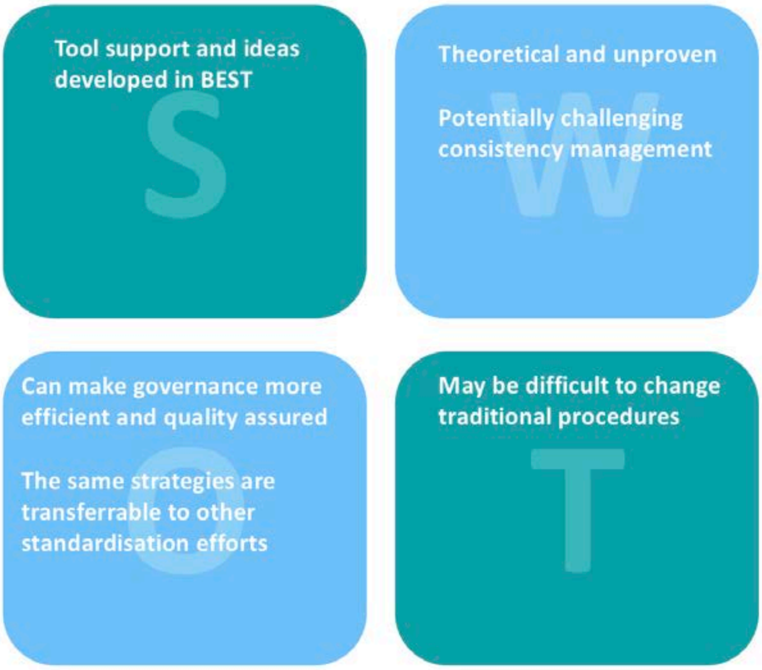
Possible mechanisms to support/fund further work:

All of the above steps would potentially be suitable for funding as one or more catalyst projects under the ENGAGE project (offering up to 60K euros for extending project results). Alternatively, they could be combined to a single TRL2 exploratory research project. It would probably be a good idea if such a future TRL 2 project included aspects related to overall governance processes, as this would give a project with a more convincing scope and greater impact.

Stakeholders:

- All actors involved in preparations for operational adoption of SWIM, particularly aspects related to compliance testing.
- Actors involved in definition of standards in ATM information modelling (e.g. AIRM, and exchange models such as AIXM, FIXM etc.).

Modularisation of information models (understandability/manageability of models, governance)



Ideas for new research directions building on work done in BEST:

1. Technical refinement: consider how the modularization tool could provide new functionality to provide suggestions for selection of the seeds for concept-based modularization. This could be based on different criteria, such as minimization of inter-dependencies between modules.
2. Make the tool available to other researchers, to test it /experiment with its application to other ontologies (already done: information on website on how to access and use the tool).
3. Use experiences and observations from other users of the modularization tool to update guidelines on how to use it effectively.
4. Establish contact with people involved in AIRM governance and co-operate with them to try to identify candidate alternative ways in which the AIRM could be split into modules. Use the modularization tool to experiment with ideas.
5. Make the relevant results of BEST available to the SWIM Governance project. [This has already been done].
6. Arrange a meeting with the SWIM Governance team to present the recommendations and enter into a dialogue about how they might influence approaches to governance in the short, medium and long term.

Potential Obstacles:

We do not foresee any particular obstacles to continuation of technical work on development of and practical experimentation with the modulization tool. When it comes to applying the tools and lessons of BEST in a governance setting, we anticipate that it may be difficult to convince stakeholders to consider moving away from traditional views and procedures.

Timescale:

Step 2 has already been started, as information has been provided on the project website and in this report. This work can continue in the immediate future.

Step 5 has also already been done: information has been sent to the leader of the SWIM Governance project. Work to follow-up on this can continue in the near future. Step 6 could be achieved within the next 6 months – but this is entirely dependent on prioritizations and plans within the SWIM Governance project.

Step 1 could be started within the next 6-18 months if appropriate resources can be found to fund the work. The work could be completed within about 12-18 months of its starting date.

Step 3 can start as soon as any feedback is received; it would be a continuous process.

Step 4 could be started within the net 6-12 months.

Possible mechanisms to support/fund further work:

Step 1 would potentially be suitable for funding as a catalyst projects under the ENGAGE project (offering up to 60K euros for extending project results). Alternatively, it could be combined to a single TRL2 exploratory research project, combining with steps 2-5 (and also with some of the ideas presented above in the section on compliance validation).

Stakeholders:

As for "Automated Compliance Verification " above – but with some emphasis on the SWIM Governance project.

4.3.3 R&D to extend the scope of BEST results in the longer term and to other domains

During the course of the BEST project we have also discussed specific application areas in which it could be relevant to combine results from BEST. Some of these application areas are brought up because of partners experiences, while others are based on interaction with reference group members. These application areas are described in the following.

Resilience Management

In the SCALES project (WPE-E.02.30) a framework for resilience management in ATM brought together theoretical principles for resilience with operational aspects of performing air traffic management. One the main results from the SCALES project was a "Resilience View" which mapped operational functions (e.g. provision of weather information) with indicators of resilience.

A future project could benefit from the ontological representation of AIRM and exchange models developed in BEST and investigate how SWIM information exchange can support resilient operations by analysing both information exchange patterns and information model syntax and semantics. This could include an analysis of which payloads/information elements are relevant to satisfy the different operational functions, data distribution strategies, data filtering (e.g. too much information can influence an ATC controller´s ability to *respond*, one of the Resilience Abilities from Resilience literature).

Alignment of semantic developments in ATM - NASA ontology and AIRM

A recent semantic technology development in ATM is the NASA ATM ontology[4]. This ontology is a key component in a system built to integrate and retrieve ATM related data from multiple governmental and non-governmental sources. The NASA ATM ontology was released in March 2018.

A future project could aim to align the AIRM ontology and the NASA ontology. This would include both (1) identifying the semantic relations between the two ontologies so that it is possible to benefit from the existence of both ontologies (e.g. in linked data applications), and (2) identifying differences that could be the basis for useful extensions on both sides. The techniques proposed in D1.2 (AIRM Compliance Validator) could be used in order to perform an automated analysis of the semantic alignment between these two ontologies.

Some initial work on this has already been done, involving consortium members from BEST and one person from NASA.

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[4] https://data.nasa.gov/ontologies/atmonto/index.html

Enhancing Semantic Containers with Artificial Intelligence

In every one of the three reference group workshops held during the project, at least one of the participants – unprompted - pointed out that artificial intelligence technologies could enhance the capabilities offered by BEST tools and concepts. The relevance is clear: BEST involves automated filtering and matching of data, sometimes from different sources – areas that are also covered by AI techniques. While, to some, this may seem “far-fetched” in the area of ATM, we are clearly seeing application of AI techniques in an ever-widening range of domains – including safety-critical areas such as healthcare - and there is no reason to believe ATM will be immune to that.

It might also be that AI techniques could benefit from the filtered information offered by semantic containers. Such a pre-filtering of input data can bring more accurate results from machine learning employed by an AI system since irrelevant (noisy) data could be filtered out by the semantic container approach.

Thus: it would be useful to investigate ways in which semantic technologies and AI techniques could be used together in the ATM domain.

Harmonised information model for multi-modal transport

A number of initiatives in earlier EU research programmes have investigated and developed harmonized multimodal information models and associated software applications (e.g. travel planners, freight management systems) for both freight and passenger transport, but then typically in the context of road, rail and maritime transport. For various reasons, airborne transport is often left out of this harmonization, despite the fact that critical planning and execution parameters could be derived from such data.

A future project could provide an inventory of relevant information models and standards, encompassing all transport modes, including the ATM models used in BEST (AIRM and exchange models). Further, the project should from this inventory develop a harmonized information model and offer recommendations on how such a model could be governed by international standardization bodies.

5 References

5.1 Project Deliverables

The public, technical deliverables produced in the project are listed in section 2.5, including their title, a short description of their content and details of how they can be accessed via the project website or, alternatively, on the CORDIS site maintained by the European Commission. The project website also contains summaries of the deliverables, and (where relevant) indications of how software, ontologies and other technical resources associated with the deliverables can be accessed.

In addition to the public, technical deliverables, the project also produced some confidential deliverables for use within the project. These are listed in section 5.3 below, see: [3], [11] and [12].

5.2 Project Publications & Participation in Events

Title [and direct link to publication, where available]	Event/ Presentation	Main Authors	Published at	Date/Place	Remarks
"Ontology-based data description and discovery in a SWIM environment." https://ieeexplore.ieee.org/document/8011928/	Integrated Communications, Navigation, and Surveillance (ICNS) 2017	Christoph Schuetz	Paper officially published via IEEE	April 18-20, 2017, Washington DC, USA	Won the "Best in track" award. Presented and published.
"Semantic Data Containers for Realizing the Full Potential of System Wide Information Management", focuses on the use-cases of a SWIM container system." https://ieeexplore.ieee.org/document/8102002/	Digital Avionics Systems Conference (DASC) 2017	Eduard Gringinger	Paper officially published via IEEE	21/09/2017, St. Petersburg, Florida, USA	Presented, published.
"Towards a value-added information layer for SWIM: The semantic container approach" https://ieeexplore.ieee.org/document/8384870/	ICNS 2018	Eduard Gringinger, Christoph Schuetz, Bernd Neumayr, Michael Schrefl, Scott Wilson	Paper officially published via IEEE	April 10-12 2018, Washington DC, USA	Presented, published.

Title [and direct link to publication, where available]	Event/ Presentation	Main Authors	Published at	Date/Place	Remarks
"Towards Scalability Guidelines for Semantic Container Management" https://dl.acm.org/citation.cfm?doid=3185768.3186302	International Conference on Performance Engineering (ICPE) 2018	Gunnar Brataas, Christoph Schuetz, Bernd Neumayr		15/04/2018, Berlin, Germany	Paper accepted, published

Title [and direct link to publication, where available]	Event/ Presentation	Main Authors	Published at	Date/Place	Remarks
"Semantics-Based Summarization of ATM Information to Manage Information Overload in Pilot Briefings"	31st Congress of the International Council of the Aeronautical Sciences (ICAS) 2018	Christoph Schuetz, Bernd Neumayr, Michael Schrefl, Scott Wilson, Eduard Gringinger		01/09/2018, Belo Horizonte, Brazil	Paper accepted. Abstract was among the limited number (around 20 out of 860) selected by members of the ICAS Programme Committee for consideration for the Special Issue. This special issue will be published in the Aeronautical Journal (the world's oldest aeronautics journal currently in production)!

Title [and direct link to publication, where available]	Event/ Presentation	Main Authors	Published at	Date/Place	Remarks
"Automated Compliance Verification in ATM Using Principles from Ontology Matching"	International Conference on Knowledge Engineering and Ontology Development (KEOD 18)	Audun Vennesland, Joe Gorman, Christoph Schuetz, Bernd Neumayr, Scott Wilson		18-20th September, , Sevilla, Spain	Paper accepted.
The US Federal Aviation Authority (FAA) and EUROCONTROL hosted the 2017 Air Transportation Information Exchange Conference (ATIEC 2017) in Brussels. The theme of the event was "Information Exchange Specifications supporting the ICAO Global Air Navigation Plan".	Air Transportation Information Exchange Conference (ATIEC 2017)	Eduard Gringinger, Frequentis		5 - 6 October 2017, Brussels, Belgium	Presented, Participated
BEST project poster I http://project-best.eu/publications.html	SESAR Innovation Days (SID) 2016	Multiple consortium members	Published at the project's website	Nov 8-10, 2016, Delft, Netherlands	
BEST project poster II http://project-best.eu/publications.html	SID Belgrade, 2017	Multiple consortium members	Published at the project's website	28 – 30 November 2017, Belgrade	Presented, Published.

5.3 Other References

[1] Project Execution Guidelines for SESAR 2020 Exploratory Research, 8 February 2016, Edition 01.00.00

[2] Horizon 2020/SJU GRANT AGREEMENT NUMBER — 699298 — BEST

[3] Project Management Plan (Confidential BEST Project Deliverable D6.2 v1.0, 28th December 2016)

[4] "System Wide Information Management" (SWIM) – a simple overview by EUROCONTROL http://www.eurocontrol.int/swim.

[5] "ATM Information Reference Model (AIRM)" -official web page by EUROCONTROL (now responsible for overseeing its further development) http://www.eurocontrol.int/articles/airm-atm-information-reference-model.

[6] Horridge, M., and S. Bechhofer. 2011. "The OWL API: A Java API for OWL Ontologies." *Semantic Web Journal* 2 (1):11-21.

[7] Object Management Group. 2014. "Ontology Definition Metamodel (ODM) v1.1." Needham, OSA.

[8] Initial System Wide Information Management. SESAR eATM portal: https://www.atmmasterplan.eu/data/atm_functionalities/18

[9] SWIM Technical Infrastructure and Profiles. SESAR eATM portal: https://www.atmmasterplan.eu/data/sub_afs/942

[10] SWIM service registry: https://eur-registry.swim.aero/services

[11] Project Handbook (Confidential BEST Project Deliverable D6.1 v1.0, 22nd November 2016)

[12] Dissemination, Communication and Project Promotion Plan (Confidential BEST Project Deliverable D4.2 v1.2, 7th March 2018)

Appendix A Acronyms and Terminology

Acronym/Term	Definition
AIRM	ATM Information Reference Model
ATM	Air Traffic Management
Ontology	Formal definition of the types, properties, and interrelationships of the entities that exist in some domain of discourse
OWL	Web Ontology Language
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SWIM	System Wide Information Management

The BEST consortium:

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Frequentis AG	
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SLOT Consulting	
EUROCONTROL	