PhD title:
The Effect of Chemical Regulations on the Aerospace and Defence Industries

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Declaration Statement

The study outlined in this thesis was carried out College of Engineering and Technology of the University of Derby, under the supervision of Doctor Kapila Liyanage and Doctor Sabuj Mallik.

This is to declare that the work stated in this thesis was done by the author, and no part of the thesis has been submitted in a thesis form to any other university or similar institution for any other degree or professional qualification.

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I declare that my thesis consists of **49,404** words (excluding references and appendix).

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Publications associated with this research

Academic Journal Paper Articles

1. Takhar, S., and Liyanage, K., (2021c). Transforming product labels using digital technologies to enable enhanced traceability and management of hazardous chemicals. *International Journal of Supply Chain and Operations Resilience*, **5**(1), pp 27-59. Available from: https://www.inderscienceonline.com/doi/abs/10.1504/IJSCOR.2021.115550.
2. Takhar, S., and Liyanage, K., (2021b). Realignment of Product Stewardship towards Chemical Regulations, the Circular Economy and Corporate Social Responsibility – a Delphi Study. *Operations and Supply Chain Management: An International Journal*, **14**(3), pp. 368-386. Available from: http://doi.org/10.31387/oscm0460309
3. Takhar, S., and Liyanage, K., (2021a). Blockchain application in supply chain chemical substance reporting a Delphi study. *International Journal of Internet Technology and Secured Transactions*, **11**(1), pp. 75-107. Available from: https://www.inderscienceonline.com/doi/abs/10.1504/IJITST.2021.112871.
4. Takhar, S., and Liyanage, K., (2020). The Impact of Industry 4.0 on Sustainability and the Circular Economy Reporting Requirements. *International Journal of Integrated Supply Chain Management*, **13**(2-3), pp. 107-139. Available from: https://www.inderscienceonline.com/doi/abs/10.1504/IJISM.2020.107845
5. Takhar, S., and Liyanage, K., (2019). The Impacts of Sustainability, Extended Producer Responsibility, and the Circular Economy on Product Pricing models. *International Journal of Commerce and Management Research*, **5**(4), pp. 12-18. Available from: http://www.managejournal.com/archives/2019/vol5/issue4/5-3-54.
6. Takhar, S., and Liyanage, K., (2018a). Framework for a Chemical Substance Reporting System. *Advances in Science, Technology and Engineering Systems Journal*, **3**(5), pp. 459-477. Available from: https://astesj.com/v03/i05/p53/.

Trade Association Requested Industry Research Paper

1. Takhar, S., (2019). Supply Chain Traceability of Substances of Concern Across the Electronics Sector Supply Chain, written for IPC and presented at IPC Impact Europe, 4th December 2019. Available from: University of Derby Library, Final report (OneDrive); IPC Impact Europe! 2019 Programme (OneDrive).

UK Government Parliamentary Office of Science and Technology Paper

1. Takhar, S. (2021). Regulating Product Sustainability. Interview, written review, and feedback on UK POST office proposals on the future of regulating product sustainability. Available from: UK POST.

PixL (Partners in Excellence)

1. Takhar, S. (2020). What is Industry and how is it regulated? Educated discussion video circulated to UK Secondary Schools during Summer 2020. Available from: PiXL.

Research Conference Papers

1. Takhar, S., (2022). Empowering digital supply chain transformation by utilizing Industry 4.0, Smart Factories, Standards, Smart Contracts and Blockchains, Proceeding of 2022 IPC Apex Expo Technical Conference. Available from: https://derby.openrepository.com/handle/10545/626234.
2. Takhar, S., and Liyanage, K., (2019b). Value chain impacts of EU Waste Framework Directive 2018/851 as a result of reporting Substances of Very High Concern from 2021, Proceeding of the 23rd Cambridge International Management Symposium (CIMS). September 2019, University of Cambridge. Available from: https://www.repository.cam.ac.uk/handle/1810/298830.
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5. Takhar, S., and Liyanage, K., (2018c). The Impact of Industry 4.0 on Supply Chains and Sustainability. 8th International Conference on Operations and Supply Chain Management (OSCM), Cranfield University, September 2018.

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7. Takhar, S., and Liyanage, K., (2018a). Competitive Product Pricing, Extended Producer Responsibility, Sustainability, and the Circular Economy. 3rd Academic International Conference on Business, Economics and Management (AICBEM) 2018, Oxford University, January 2018.
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Abstract / Synopsis

This thesis investigates the impact of chemical regulations on the Aerospace and Defence (AD) sector, via examination of chemical substances consumed in the manufacture articles (products). The complex nature of AD article design, approval and manufacture makes the process of chemical substance identification very complex, involving multiple actors in multiple sectors, utilising multiple sub-systems to collect, ingest, analyse, and report data. Through a mixture of Author personal experiences working within the AD sector for nearly 19 years, and the investigation of literature around current state data collection and data quality issues across the AD sector determined the need for a common framework to support a harmonised approach to data elements required to identify the impact of chemical regulations against articles manufactured for the AD sector.

This thesis asks four research questions covering four key research objectives. The first research objective pertains to the investigation of existing methodologies used to identify chemical substances within AD articles. The second research objective pertains to the investigation of chemical regulations applicable to the AD sector. The third research objective pertains to the development of a framework to analyse the impact of chemical regulations. The fourth research objective pertains to evaluating the performance of the proposed framework using simulation. Research activities undertaken covered the literature review, three Delphi studies examining the data model, potential automation of data collection via blockchains and anticipated system output reports.

The developed framework includes (1) a data model which can applied by AD organisations to develop new / existing systems; (2) to ingest data via harmonized data load templates which can ingest data from multiple sources, covering internally defined and externally sourced AD articles; (3) enabling the applicable system where the data model is applied against to generate standard system output reports to identify potential risks posed against a given chemical regulation, (4) to enable corrective actions to be undertaken; (5) perform reporting obligations to downstream users of products; (6) investigate the use of alternative substances to replace the identified hazardous substances. The data model presented is platform agnostic enabling deployment and reporting to occur on any applicable platform.

Acknowledgements

I dedicate this PhD thesis to my wife Karenjit Takhar, my son Avinash Takhar and the rest of my family for their enduring support and commitment throughout my life and during this research study.

I would also like to thank Assent for allowing me the opportunity and resources to complete this research study. I would like to thank all the companies, trade associations, standards bodies, academics, research institutions and conferences which were engaged in, during the study for providing valuable insights and resources that aided the development of this research study.

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List of Abbreviations

The following list of abbreviations defines the terms, acronyms and abbreviations used within this research study from the: (1) Aerospace and Defence (AD) sector; (2) Engineering sector; (3) Electronics sector; (4) software design, and (5) chemical regulation terminology.

Acronym / Abbreviation / Term	**Meaning**
A	
ACS	American Chemical Society.
AD	Aerospace and Defence.
ADS	UK Aerospace, Defence, Space and Security industries trade association.
AI	Artificial Intelligence.
ASD	Aerospace and Defence Industries Association of Europe.
AR	Authorised representative, see OR.
Article (*regulation*)	Topic area descriptions used within European regulations and directive.
Article (*product, assemblies, part numbers, components*)	Defined under EU REACH 1907/2006, article 3(3) as 'means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition'.
Authorisation	An approval to make use of a chemical substance which is being controlled for use. Use of an authorisation occurs when (1) a manufacturer needs additional time to investigate the use of alternative chemicals, or (2) no alternative chemicals exist, with the controlled substance needed for safety performance measures.
B	
B	Billion.
BOM	Bill Of Materials.
BSi	British Standards Institute.
C	
CAA	UK Civil Aviation Agency.
CAD	Computer Aided Design.
CAHRA	Conflict Affected and High-Risk Area, defined under EU Conflict Minerals Regulation 2017.
Cal Prop 65	California Proposition 65 first published 1987.
CAM	Computer Aided Manufacture.
CAS	Chemical Abstract Number, maintained by ACS, is the most widely referenced chemical registration numbering index.
CBI	Confidential Business Information.
CEFIC	European Chemical Industry Council.
CHEMSEC	International Chemical Secretariat.
CLP	Classification, Labelling and Packaging Regulation (EC) 1272/2008.
CMMI	Capability Maturity Model Integration.
CMR	Carcinogens, Mutagens and Reprotoxic substances.
CO_2	Carbon Dioxide.
CoRAP	Community Rolling Action Plan.
CRM	Critical Raw Materials.
CSR (*strategic*)	Corporate Social Responsibility.
CSR (*chemical regulations*)	Chemical Safety Report.

List of Abbreviations

Acronym / Abbreviation / Term	Meaning
D	
DEFRA	Department for Environment, Food & Rural Affairs (UK).
DMAIC	Define, Measure, Analyse, Improve and Control.
DSL	Declarable Substance List (interchangeable term with Reportable Substance List).
E	
EASA	European Union Aviation Safety Agency.
EC (*political*)	European Commission.
EC (*chemical*)	European Community number, legacy European chemical numbering system, consisting of NLP, EINECS and ELINCS inventories. In use between 1971 and 1981, EC numbers may be used in conjunction with CAS numbers within certain chemical regulations to identify chemical substances.
ECHA	European CHemicals Agency.
ECHA SCIP	ECHA Substances of Concern In articles, as such or in complex objects (Products).
ED	Endocrine Disruptor.
EDA	European Defence Agency.
EHS	Environmental, Health and Safety.
EINECS	European Inventory of Existing Commercial Chemical Substances.
ELINCS	European List of Notified Chemical Substances.
EOL	End of Life.
ERM	Enterprise Resource Management.
ERP	Enterprise Resource Planning.
ESDS	Extended Safety Data Sheet.
ESG	Environmental, Social, and corporate Governance.
ESO	European Standards Organisation.
EU	European Union.
EU Directive	An agreed method of processing tasks and enforcement, where EU member states implement local transposition regulations to implement.
EU EDA	European Defence Agency.
EU GDPR	EU General Data Protection Regulation 2016/679 lays down strict requirements to control data that can identify and make decisions on individuals.
EU REACH	EU Registration, Evaluation, Authorisation, and restriction of Chemicals (REACH) Regulation 1907/2006.
EU Regulation	Binding legislative acts, which become the law applied in its entirety across all EU member states.
EU TFEU	EU Consolidated version of the Treaty on the Functioning of the European Union, C 326/49 (2012).
EUON	European Union Observatory for Nanomaterials.
F	
FAA	Federal Aviation Authority.
FBA	Federated Byzantine Agreement.
FFF	Fit, Form, Function.
FMD	Full Material Declaration.
FSD	Full Substance Disclosure.
FTE	Full Time Employee.
G	
g	Gram, metric unit of mass, defined within data templates to enable calculation of the amount of a given chemical substance on its own, within a mixture or material, to within the overall weight of a finished article.
GADSL	Global Automotive Declarable Substance list.

List of Abbreviations

Acronym / Abbreviation / Term	**Meaning**
GHG	Green House Gases.
GT	Gigatonnes.
H	
HSE	Health, Safety, and the Environment.
HTTPS	Hypertext Transfer Protocol Secure.
I	
IAEG	International Aerospace and Environmental Group.
IAEG AD-DSL	IAEG Aerospace and Defence – Declarable Substance List.
IATA	International Air Transport Association.
IC	Integrated Circuit.
IEC	International Electrotechnical Commission.
IET	Institute of Engineering and Technology (UK).
IETP	Illustrated Electronic Technical Publication.
Intermediate	An individual chemical substance or mixture, which is combined with other chemical substance or mixtures, to generate new chemical substances. Within certain chemical regulations, intermediates are not considered to be in scope or any control measures, only the final substances that appear on a finished article.
IoT	Internet of Things.
IMDS	International Material Data System.
IPC (*aerospace*)	Illustrated Parts Catalogue.
IPC (*electronics*)	Institute of Printed Circuits.
IPCS	International Programme on Chemical Safety.
IRL	Integration Readiness Level.
ISO	International Organisation for Standardization.
IT	Information Technology.
ITIL	Information Technology Infrastructure Library.
J	
JAMA	Japan Automobile Manufacturers Association.
JAPIA	Japan Auto Parts Industries Association.
JIT	Just-In-Time.
K	
K	Thousand.
Kg	Kilogram.
L	
LED	Light Emitting Diode.
LLP	Life Limited Part.
M	
M	Million.
Manufacturer or producer	Defined under EU REACH 1907/2006, article 3(4) as 'producer of an article: means any natural or legal person who makes or assembles an article within the Community'.
Max	Maximum.
Min	Minimum.
Mixture	Defined under EU REACH 1907/2006, article 3(2) as 'means a mixture or solution composed of two or more substances.'
MPA	Master Purchasing Agreement.
MRL	Manufacturing Readiness Level.
MRO	Manufacturing, Repair and Overhaul.
MS	Microsoft.

List of Abbreviations

Acronym / Abbreviation / Term	Meaning
MSCA	Member State Competent Authority.
MSDS	Material Safety Data Sheet.
N	
NASA	National Aeronautics and Space Administration.
NATO	North Atlantic Treaty Organization.
NGO	Non-Governmental Organisation.
NLP	No-Longer Polymer list of substances.
O	
ODM	Original Design Manufacturer.
ODS	Ozone Depleting Substances.
OEM	Original Equipment Manufacturer.
OEL	Occupational Exposure Limit, used when assessing the hazards of using a specific chemical substance.
QMS	Quality Management System.
OR	Only Representative, a third party enabling companies to perform applicable notifications under a regulation, sometimes referred to as an AR.
P	
PBFT	Practical Byzantine Fault Tolerance.
PDCA	Plan Do Check Act / Adjust.
PDM	Product Data Management.
PDF	Portable Document Format.
PHM	Prognostics Health Management, consisting of software and sensors to monitor critical modules on aircraft.
PIC	Prior Informed Consent, based on recording movements of hazardous waste where the nation transmitting hazardous shipments has agreements with the receipting nation agreeing to receive the hazardous shipments.
PII	Personally, Identifiable Information, needs to be controlled as a result of EU GDPR requirements.
PLM	Product Lifecycle Management.
PoA	Proof of Authority.
PoET	Proof of Elapsed Time.
POP	Persistent Organic Pollutants (POP), globally agreed treaty aimed at eliminating or restricting the use of POP chemicals, signed in 2001 and coming into effect since 2004.
PPAP	Production Part Approval Process, used widely within the Automotive sector, requiring suppliers to report on any changes relating to a supplied articles. AD sector configuration management systems mimic this behaviour.
Q	
QR Code	Quick Response Code.
Qty	Quantity.
R	
RCRL	Readiness Compliance Readiness Level.
RDMS	Relational Database Management System.
Registration	A form of notification made to a regulator which details the properties of the chemical and may contain a CSR (chemicals) detailing any risks. Registrations are triggered in certain chemical regulations where a annual 1 ton threshold is defined where the given chemical substance is used on its own, within mixtures and materials, and / or within finished products, produced or imported into a given region.

List of Abbreviations

Acronym / Abbreviation / Term	Meaning
Regrettable Substitution	The act of substitution which results in the alternative substance, containing similar hazardous properties as the original substance which had been substituted.
Restriction	Used to denote if a chemical substance is restricted from use, its entirety, or a specific use case.
RFID	Radio Frequency IDentification.
S	
SAE	Society of Automotive Engineers.
SBO	Standards Body Organisation.
SCCSR	Supply Chain Chemical Substance Reporting.
SCD	System Context Diagram.
SCM	Supply Chain Management.
SCN	Supply Chain Network.
SCOR	Supply Chain Operations Reference.
SCRL	Supply Chain Readiness Level.
SDLC	Software Development Life Cycle.
SDS	Safety Data Sheet.
SME	Small Medium Enterprise.
SPM	Supplier Performance Management.
SIA	Supplier Integrity Assessment.
SIPOC	Supplier Input Process Output Customer.
SQL	Structured Query Language.
Substance	Defined under EU REACH 1907/2006, article 3(1) as 'substance: means a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition'.
Substitution	The principle of replacing a hazardous chemical with non-hazardous chemicals.
SVHC	Substance of Very High Concern.
T	
T	Trillion.
TDA	Technical Design Authority.
TQM	Total Quality Management.
TRL	Technology Readiness Level.
U	
UI	User Interface.
UK	United Kingdom.
UK CIA	UK Chemicals Industries Association.
UK REACH	UK implementation of EU REACH type regulation.
UN	United Nations.
UNEP	UN Environmental Program.
UNFCCC	UN Framework Convention on Climate Change.
UN GC	UN Global Compact.
UN GHS	UN Globally Harmonized System of Classification and Labelling of Chemicals.
UN SAICM	UN Strategic Approach to International Chemicals Management.
UN SDG	UN Sustainable Development Goals.
UoM	Unit of Measure.
US	United States.
US NAS	US National Aerospace Standard.

List of Abbreviations

Acronym / Abbreviation / Term	**Meaning**
US TSCA	US Toxic Substances Control Act 1976.
USMCA	United States Mexico Canada Agreement.
UVCB	Unknown or Variable Composition.
V	
vPvB	Very Persistent or Very Bio accumulative.
W	
WEF	World Economic Forum.
WHO	World Health Organisation.
WIP	Work In Progress.
X	
XML	eXtensible Markup Language.

Chapter 1: Introduction

1.1 Author Background

The motivation for this research stems from the author working within Aerospace and Defence (AD) sector for nearly 19 years, during which time the author: (1) managed production cells; (2) supported and developed large enterprise level IT systems covering engineering design (CAD / PDM / PLM), document record management and technical publication systems; (3) been responsible for the development of a global reporting system to identify the use of reportable chemicals under the EU Registration, Evaluation, Authorisation of CHemicals (REACH) regulation (EC) No 1907/2006 (EC, 2006a); (4) been responsible as a working group chair within the International Aerospace and Environment Group (IAEG) to coordinate the data capture and reporting requirements across the entire AD sector; (5) following the activities within IAEG, the Author, then formed and chaired an international data exchange standard, within the Institute of Printed Circuits (IPC), the largest trade association within the global electronics sector, the standard was the IPC-1754 Material declaration standard for the AD sector, initially published in 2018. The author is currently: (1) the EU chair of IPC-1754; (2) represents the UK Institute of Engineering and Technology (IET) within the British Standards Institute (BSi) aerospace standards committees; (3) sits on the IET technical advisory panel for the AD sector; (4) represents BSi within the International Standards Organisation (ISO) / Aerospace, Space and Defence (ASD) standards; (5) supports the European CHemical Agency (ECHA) in the development of the ECHA Substances of Concern In articles as such or in complex objects (Products) (SCIP) database implemented as part of the EU Waste Framework Directive (EU) 2018/851 (EC, 2018b) as part of the SCIP IT expert working group; (6) supports the UK Departments for Environment, Food & Rural Affairs (DEFRA) as part of the IT stakeholders group, with the development of the UK REACH system implementation following Brexit, all of these activities are undertaken voluntarily by the author.

1.2 Research Motivation

It was during the development phase of IPC-1754 data exchange standard, the author, came to the firm belief, that whilst AD supply chain actors would begin to share data in a harmonised format via the IPC-1754 data exchange standard, there was a clear lack of understanding amongst several AD supply chain actors on how to collate, analyse, assess, and report internal data in a consistent manner. This belief was further expanded whilst

conducting this research study and engaging with numerous AD supply chain actors as part of the author's current role.

1.3 Research Problem

The AD sector covers a wide range of organisations supplying articles to the Civil and Defence sector markets. Author conducted analysis in Appendix [1], investigated typical parts on aircraft manufactured between 1957 and 2019, identifying: (1) typical narrow body aircraft has between 400K to over 600K finished articles, with; (2) typical widebody aircraft has over 1.2M to over 3.4M finished articles, the Airbus A380 aircraft has in excess of 5M finished articles. The finished articles on aircraft can consist of several times the typical finished article number amounts, due to: (1) finished articles may contain multiple lower-level assemblies and lower level articles; (2) the lower level articles may themselves be formed from several lower level article numbers. Typical article definitions within the AD sector consist of geometry drawing(s) which defines the fit, form and function of the article, together with referenced material and process specifications which call out the required chemical substances, mixtures, and materials to be used. Multiple sub-systems within a typical AD organisation record the required information needed to support a chemical reporting system for an AD organisation. Increasing outsourcing further proliferates the amount of data that organisations need to collect to remain compliant with any applicable chemical regulation. Chemical regulations exist to monitor, control, and restrict the amounts of hazardous chemical substances in use to protect humans and the environment from potential impacts of continued use of the hazardous chemicals. Increasing global chemical regulations require industry to identify the use of hazardous chemical substances (Botos, Graham, Illés, 2018; Regulation of chemicals wiki, 2019). The list of regulated substances introduced by chemical regulations will continually grow over time. As each new chemical regulation arises / a new chemical substance is added to an existing chemical regulation, AD organisations need to identify the impacts of the chemical regulation against their ability to procure, import, export, and distribute articles across local, regional, and international boundaries. A key theme when engaging within the AD and several other sectors is a lack of awareness of the required of chemical reporting which is required. Organisations have tended to focus on collecting data from a supply chain as a higher priority, than actually developing systems which observe the wider uses of chemicals within an organisation, for example: if a chemical becomes reportable, under a given chemical regulations, AD organisations may focus on just collecting data on the amount of the chemical substance

appears on a finished article, ignoring the need to understand if the chemical either remains on the finished article or is a process chemical. In the event of chemical regulation further restricting a chemical substance, then there is a real business continuity risk that the manufacturing process use of a chemical may have been completely ignored, meaning the organisation may have replaced the chemical substance on the finished article, but cannot then manufacture the article, as a key process chemical can no longer be used. AD organisations need a system that can identify chemical substances which are: (1) held in physical stock as chemical substances, mixtures, and materials; (2) consumed into internally manufactured articles, and; (3) consumed from externally procured products into finished articles. At its core, this research study pertains to a real world issue, the consistent identification of chemical substances used on their own, within mixtures, materials, by examining both external supply chain data; as well internal definition data for articles (*the legal term used in chemical regulations used to describe products*); which are then cross referenced against chemical regulation substance lists; to identify potential risks; which via the suggested review board activities enables appropriate risk mitigation activities to be identified and enacted upon, in a much more efficient manner than current state practices, within the AD sector.

1.4 Research Aim, Objectives, and Questions

1.4.1 Research Aim

The main aim of this research is:

> **To develop a conceptual framework enabling identification of articles (products) potentially at risk from chemical regulations supporting decision making processes for AD organisations.**

1.4.2 Research Objectives

The research objectives are shown in Table [1-1]:

Table 1-1: Research objectives and conceptual methodology

Research objectives
[RO1] To investigate existing methodologies used to identify chemical substances within AD articles.
[RO2] To investigate chemical regulations that may impact the manufacture of AD articles.
[RO3] To develop a framework to analyse the impact of chemical regulations on AD articles.
[RO4] To evaluate the performance of the proposed framework using simulation.

1.4.3 Research Questions

The research questions are shown in Table [1-2]:

Table 1-2: Research questions

Research questions
[RQ1] How can issues with current state data collection and analysis of chemical substances within AD articles be identified?
[RQ2] How should AD actors (internal and supply chain) and data elements be conceptualised in a framework?
[RQ3] How can data be ingested from multiple sub-systems, correlated, reviewed and assessed in a framework?
[RQ4] How should the framework be implemented within a typical AD organisation to identify any potential impacts posed by chemical regulations?

1.5 Chapter Summary

This chapter introduced the research study. The objective of this research was to develop a conceptual framework to support the identification of potential risks posed by chemical regulations in the AD sector. This thesis is organised into eight chapters as shown in Figure [1-1].

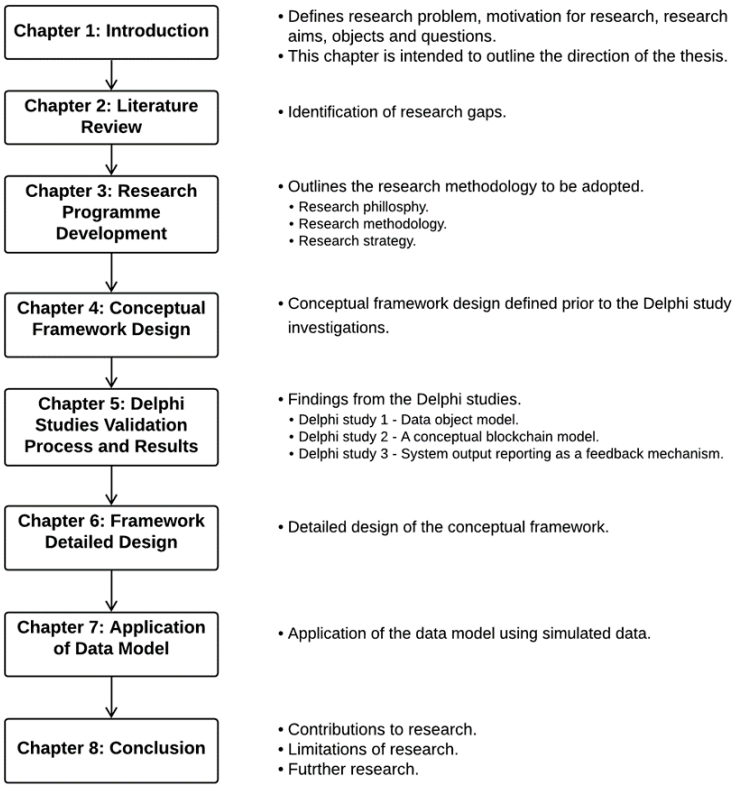


Figure 1-1: Organisation of Thesis

Chapter 1, identified the research problem, aim, objectives and questions, as shown in this chapter, Chapter 2, the literature review, organised against the research questions, undertook a thorough review of current state behaviours, theories, models, and empirical research was conducted, observing actors, roles, data flows, chemical regulations towards identifying the effect of chemical regulations on the AD sector.

Chapter 3, the research programme development examined the research context, research philosophy, worldviews focusing on transformative for regulatory changes and pragmatic worldview for the overall research, research methods, research strategy followed by the development of the theoretical and conceptual frameworks, utilising a data model to ingest data and generate applicable system output report highlighting potential risks, which were explored and verified by experts as part of the series of Delphi studies.

Chapter 4, the conceptual framework design, utilised theoretical methods and the authors experiences from Engineering and IT, encompassing systems design, stakeholder analysis, regulatory compliance readiness level, sources of data, presenting the developed theoretical and conceptual frameworks.

Chapter 5, Delphi studies validation process and results, examined three distinct Delphi studies, utilising expert feedback relating to (1) the data model; (2) potential use of a blockchain, and; (3) examine potential reporting. The logic of (1) was to develop the core data model to ingest data in a harmonised format, performing applicable system analysis tasks, to then generate a set of system output reports (2). Delphi study (2) was conceptualised within the Delphi study only as a potential means of automating the data collection activities.

Chapter 6, the detailed framework design, organised against the research questions, discussed the end-to-end activities within the conceptual framework, covering identification of definitions, collection of internal business function article related data, as well ingesting data collated from the supply chain. The resultant system analysis running against applications, generating system output reports that present where applicable risks by highlighting regulated chemical substances. Suggested additional analysis and risk management activities were then explored in terms of review boards, assessing AD article related information in the context of business function activities. Finally suggested external engagement was outlined, to be utilised in the event a chemical substance is targeted via consultations for more restrictive control measures.

Chapter 7, the application of the data model, utilised representative test data to walk through the process of data ingestion, internal review, followed by system output reports presenting possible risks, to be addressed where applicable with additional analysis as part of a review board processes, which are assumed as undertaking logical risk mitigation actions for the

AD organisation, where AD articles are identified as containing chemical substances identified by chemical regulations.

Chapter 8, summarises the main findings of the research in addressing the research questions, and the main contributions of this study. The chapter concludes with a discussion of the limitations of this study as well future research directions.

Chapter 2: Literature Review

2.1 Introduction

This chapter presents the literature review. The structure of this chapter is shown in Figure [2-1], detailing main sections with a brief explanation.

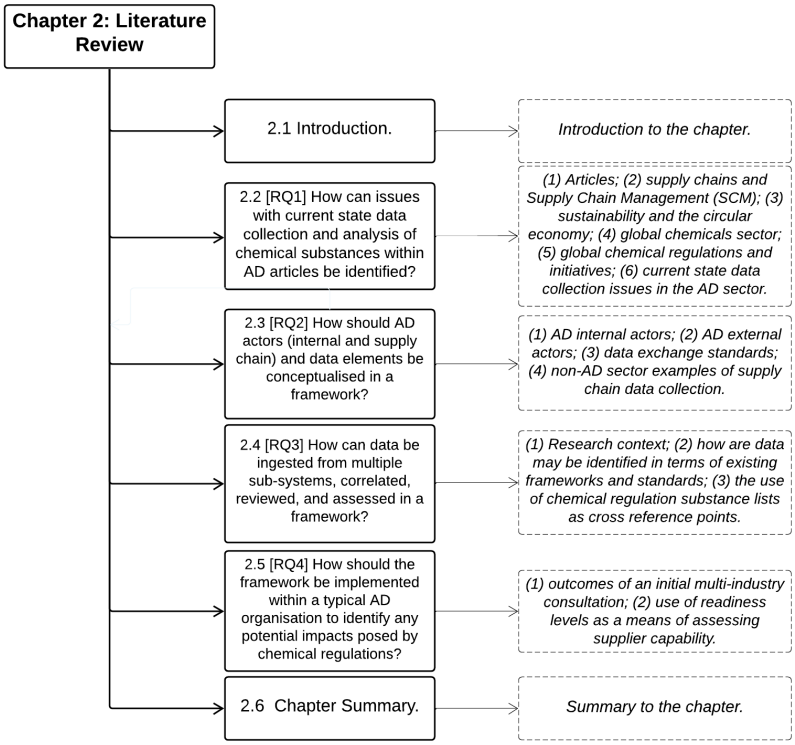


Figure 2-1: Chapter 2 structure

The chapter underpins the development of the research questions and the conceptual framework model.

2.2 [RQ1] How can issues with current state data collection and analysis of chemical substances within AD articles be identified?

This section presents current state issues in terms of the identification of chemical substances in AD articles. section 2.2.1 identifies the term article, as defined within a chemical regulation. Supply chains and Supply Chain Management (SCM) are examined in section 2.2.2. Sustainability and the circular economy are examined in section 2.2.3. The global chemicals sector is examined in section 2.2.4. Global chemical regulations and initiatives are examined in section 2.2.5. The global AD sector is examined in section 2.2.6. Current state data collection issues in the AD sector are examined in section 2.2.7.

2.2.1 Articles

An article can be described as: (1) a physical item such as a chemical substance, mixture, material, article (semi-component, component, part number, assembly, etc.) which are either manufactured for sale on their own, or collated with other articles to produce higher-level finished articles (Takhar and Liyanage, 2018a; Takhar and Liyanage, 2018b); (2) a standard type article can be described as consisting of a uniform design / composition with less variation where a customised article can be described as exhibiting high variation (Fisher, et. Al., 1997); (3) the uniqueness of an article relates to how easily it can be replicated by competitors within the same marketplace (Porter, 1980; Lamming, et. Al., 2000). Articles are produced according to some form of definition which states: (1) required geometry sizes; (2) machining data; (3) material (appearing on the finished article) or process (used in the process of manufacture) specification(s) which state required substance(s), mixture(s) or material(s). Dependent on the industry context, specifications may be either highly defined (unique substance / mixture / material to a specification) or loosely defined (multiple substance / mixture / material options).

2.2.2 Supply chains and Supply Chain Management (SCM)

A supply chain can be considered a collection of actors providing articles and services which flow, from a point of origin to an end consumer (Wagner and Sweeney, 2010). The term '*Article Transformation Cycle*' describes the process of taking raw materials, processing substances and mixtures to produce finished articles. Figure [2-2] depicts the article transformation cycle (Takhar and Liyanage, 2017a), which entails identifying the supply of raw materials which are then consumed by other manufacturers to produce articles which are then distributed and sold to consumers. The flow of goods and services within a supply chain, can entail multiple actors (Skinner, 1978; Porter, 1980; Johnson and Scholes, 1988; Beamon, 1998; Min and Zhou, 2002).

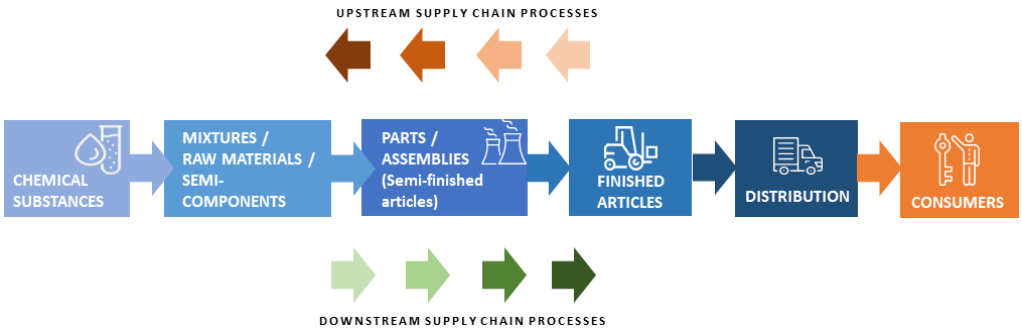


Figure 2-2: The 'Article Transformation' Cycle
Source: Adapted from Takhar and Liyanage (2018).

The traditional focus of supply chains entailed: (1) procurement of articles from regional supply chains at the lowest prices; (2) enable operational and process efficiencies; (3) obtaining competitive advantage over competitors; (4) producing high quality articles in the highest volume amounts at the lowest cost price; (5) waste production materials are not recycled; (6) articles have a defined lifespan; (7) at the end of life (EOL) an article is disposed of with minimal recycling taking place, to generate continual growths in profits (Porter, 1980; Johnson and Scholes, 1988; Beamon, 1998; Min and Zhou, 2002). Traditional SCM literature provides a basis to enable examination of an organisation internally and its position within a given marketplace, observing the need to: (1) ensure the alignment of supply chains, in terms of the articles being produced and subsequently sold to consumers; (2) reduce the lead times and costs in relation using lean manufacturing methodologies; (3) ensuring the quality of manufactured articles (Gale, 1960; Skinner, 1978; Porter, 1980; Goldratt and Cox, 1986; Deming, 1986; Johnson and Scholes, 1988; Porter 1990; Elkington, 1997; Spear and Bowen, 1999; Beamon, 1998; Hines, et. al., 2004; Sako, 2004).

2.2.3 Sustainability and the circular economy

The Brundtland report (WCED, 1987) depicted a correlation between increasing mass production of articles and the rapid depletion of natural resources. The Brundtland report highlighted the need for: (1) sustainable development; (2) environmental protection; (3) economic growth, and social equity; (4) governments, industry and society needing to work together towards changing consumer behaviours towards sustainability (WCED, 1987; UNEP, 2011). Increasing media coverage resulted in increasing pressure from Non-Governmental Organisations (NGOs), consumer groups and consumers, which in turn made manufacturers aware of the need to produce environmentally friendly articles which meet pressure to for safer and more environmentally friendlier articles, this in turn led to the development of green supply chain management (Kanchanapibul, et al, 2014; Joshi and Rahman, 2015; Kumar and Rahman, 2015). The United Nations (UN) has led the global adoption of sustainability initiatives in the form of the UN Sustainable Development Goals (SDGs) launched in 2016 (UN, 2020), providing an enlarged set of objectives extending from the original Brundtland report. The UN SDGs consist of 17 high level goals and over 165 lower level targets at global, regional, and national levels. The UN SDGs have formed the basis for governments to implement regulations and targets in alignment with the mandatory and optional targets, as well enabling industry to work voluntarily towards those same objectives via the UN Global Compact (GC) (UN, 2021). The UN has published several high-level reports highlighting the overall progress being made towards the UN

SDGs and UN GC (UN, 2015; UN, 2016; UN, 2019i; UN, 2019j). Several sustainability indices have been created in response to the UN SDGs, to aid industry to meet sustainability targets and promote sustainability credentials such as the Dow Jones Sustainability Index (Robecosam.com, 2020), GRI Standards (GRI, 2020) and Responsible Minerals / Labour / Factory initiatives (RBA, 2020). Sustainability indices can vary widely in terms of scope, size, and complexity. Organisations often invest less time in developing clear strategic directions against which UN SDGs they should readily work towards. Organisations have tended to adopt whichever sustainability indices requested by customers or are viewed as the benchmark standard for a given industrial sector, where too much emphasis is then placed on achieving higher ratings against sustainability index, without necessarily developing a long-term strategic direction enabling organisations to become truly sustainable (Grecu, 2015). Sustainability researchers stress the need to balance sustainable activities undertaken, to decouple economic activity with resource consumption, enabling reduced environmental impacts and increase societal benefits (UNEP, 2011; Fleming, et al., 2012; Ortiz-de-Mandojana and Bansal, 2016; Schandl, et al., 2016; Evans et al., 2017; UN, 2019h). The circular economy model proposes a shift in a new paradigm, moving away from the traditional linear economic model, towards open-loop manufacturing systems, as shown in Figure [2-3]. Key aims of the circular economy include: (1) designing waste out from article lifespans, using the R-imperatives: (a) reduce consumer demand for new articles and manufacturer use of required scarce resources; (b) increase consumer article resale and reuse of EOL articles; (c) repair EOL articles for sustained usage; (d) manufacturers refurbish EOL articles to be placed back onto the marketplace; (e) apply materials and update components to remanufacture EOL articles to new standards; (f) take EOL articles, disassemble repurpose articles for new uses; (g) apply recycling activities to EOL articles to create new secondary raw materials, where the only waste that ends up in landfill sites are materials which cannot be recycled; (2) over time articles will become designed to last longer, with less need for disposal; (3) articles will contain materials that exhibit highly recyclable content; (4) the recycled content will generate secondary raw materials which can be reused in the production system; (5) secondary raw materials enables scarce materials to be sustained and used in the creation of new articles.

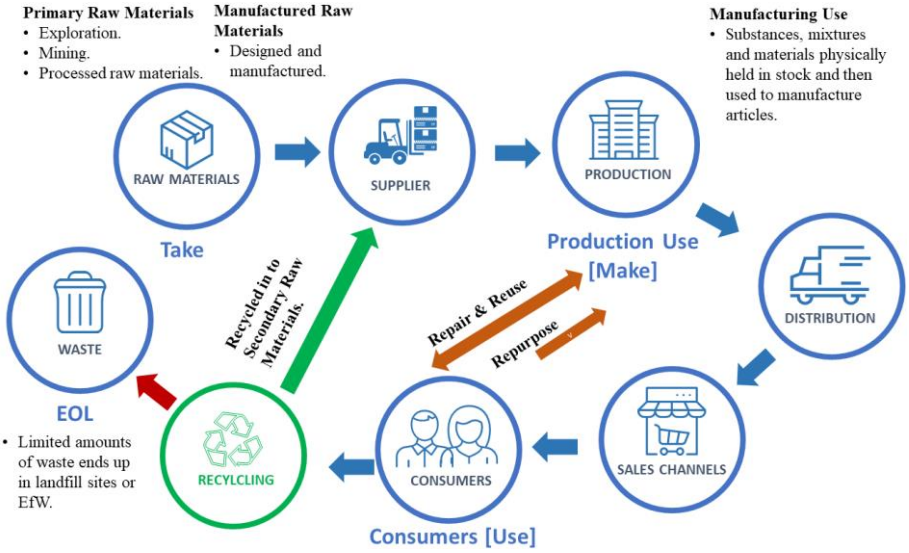


Figure 2-3: The circular economy model
Source: Adapted from The Government of Netherlands, 2019.

A synergy exists between the circular economy and sustainability, both focus on: (1) designing environmentally sound articles which do not consume scarce substances or contain hazardous substances; (2) minimizing environmental impacts of production, reducing energy consumption and waste; (3) promote the use of increased recycling and use of secondary raw materials (EC, 2015; Zeng, et al., 2017; Reike, et al., 2018; Ellen MacArthur Foundation, 2019). The consistent norms in the adoption of sustainability and circular economy practices are: (1) enhanced stakeholder engagement; (2) increased supply chain integration; (3) increased reputation and brand awareness; (4) increased customer loyalty; (5) potential application of premium pricing upon products and services (Takhar and Liyanage, 2018d).

2.2.4 Examination of the global chemicals sector

The periodic table was first developed in 1869, contains 118 elements (RSC, 2021) which have spawned more and more new chemical substances. Since the end of the second world war, the rate number of new chemical substances being placed onto the marketplace has grown exponentially decade upon decade. The speed at which new chemical substances being developed correlates directly with the pace of innovation in the marketplace, as article manufacturers compete with one another. During the short duration of this research study, the number of substances recorded in the global Chemical Abstract Service (CAS) registry data has grown significantly from 2017, where 129M chemicals were registered, through to 2021, where 181M chemicals are now registered (Takhar and Liyanage, 2017; Takhar and Liyanage, 2018a; CAS, 2021). New chemical substances are being created and registered at a daily rate of several ‘0000s. There is a correlation between increasing manufacturing

output requiring increased consumption of chemical substances, mixtures, and materials to produce articles, results in an increased rate of Green House Gas (GHG) emissions, between 1995 and 2015, 80% of GHG emissions were estimated to be linked with material use in construction and manufactured goods (UN, 2019h). Official statistics showed in 2013, the chemicals sector produced 26 key chemical products, which consumed 75% of the sectors energy use and accounted for nearly 90% of the GHGs generated by the sector (EC, 2017a). Increasing concerns directing polices towards greater efficiencies in the use of materials has been raised as means to enable a reduction in GHG emissions (UN, 2019h; EC, 2017b; WEF, 2020). The use of oil-based products such as diesel and gasoline have been identified as causing 35% of GHG emissions, where it was identified that to reduce demand for fossil fuels by increasing emission taxes (IMF, 2015). The AD sector has been identified as producing over 3% of all GHG emissions from all EU member states (including the UK) (EEA, 2019). Key concerns for the AD sector remain (1) where the use of aircraft fuel, namely Kerosene results in high volumes of hazardous gases CO_2, NO_x, SO_2, being emitted, and; (2) increased noise pollution as a result of air travel in terms of increasing use of aircraft and the noise generated, increasing pressures to control noise pollution has come from the EU (EC, 2002; EC, 2008b; EC, 2016) and the WHO (WHO, 2018). The size of the chemicals sector is examined in Table [2-1]. The global chemicals sector had prior to the Covid-19 pandemic been growing consistently, the sector has reported the impact of Covid-19 in 2020 as seeing a decline of 4.4% for the chemicals sector compared to an overall decline in manufacturing output in the EU-27 member states of 10.6% for the first 8 months of 2020 (Cefic, 2020).

Table 2-1: Global Chemical Sector Size

Year	Global sales figures	EU27 market share	USA market share	China market share	Japan market share	South Korea market share	Source(s)
2016	€3,283Bn	14.6%	13.9%	39.4%	5.1%	3.3%	Cefic, 2021a; Cefic, 2021b.
2017	€3,413Bn	15.7%	13.6%	38.5%	4.4%	3.4%	
2018	€3,525Bn	15.6%	13.2%	38.6%	4.7%	3.7%	
2019	€3,669Bn	14.8%	13.8%	40.6%	4.6%	3.2%	

2.2.5 Examination of global chemical regulations and initiatives

2.2.5.1 Overview of regulations

Regulations evolve from policy makers in response to pressures and concern over environmental impacts raised by consumers, media, and NGOs, over the behaviour of industry, which exists to generate increased profits and returns to stakeholders by generating

increased manufacturing output. Regulations and standards exist to present society with a set of norms to maintain. The term chemical regulation covers a range of regulatory tools aimed at identifying, monitoring, controlling, and limiting the use of the most hazardous chemicals of concern. Key aspects of chemical regulations can be identified as: (1) understand industrial use of all chemicals; (2) identify chemicals of concern, which are those chemicals, that based on their composition and potential hazards require additional monitoring and review; (3) understand how chemicals of concern are being used across a given supply chain sector to produce finished articles; (4) understand potential exposures from using, consuming articles that contain chemicals of concern throughout an article's active lifecycle and EOL states, identifying any issues to humans and environmental release scenarios; (5) identify additional control measures to the more hazardous chemicals of concern. Figure [2-4] depicts a basic correlation between: (1) chemical disasters; (2) concerns over the impact of hazardous chemical use on the environment; (3) concerns over climate change, and; (4) resultant regulatory control measures.

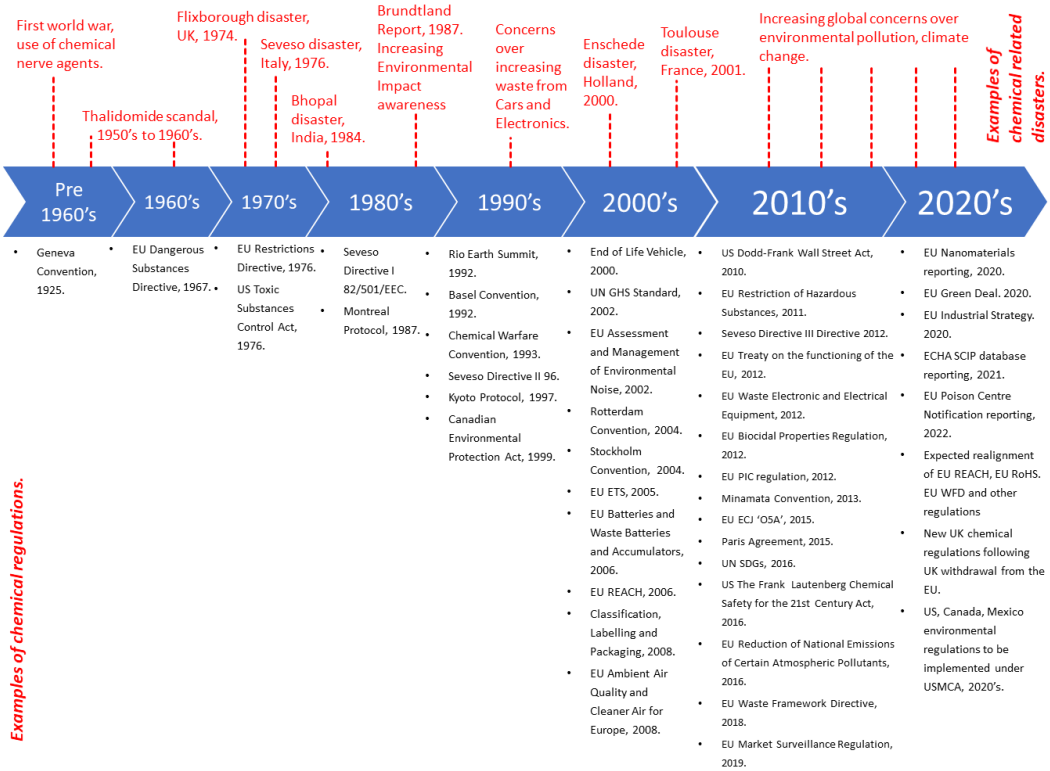


Figure 2-4: Chemical disasters, Concerns and Regulatory actions

Chemical regulations define a regulatory framework that define: (1) the required reporting obligations that manufacturers and importers need to comply with; (2) monitoring of chemical substances; (3) controlling and / or restrict the use of more hazardous substances; (4) the activities of regulatory bodies to enforce the industry control measures (Botos,

Graham, Illés, 2018; Regulation of chemicals wiki, 2019). Chemical regulations implement data reporting requirements upon industry to identify: (1) known uses for a chemical substance; (2) determine appropriate storage, handling, use and disposal instructions relating to chemical substance are identified internally and generated for downstream article users; (3) identification of risk assessment measures from using a chemical substance; (4) assess impacts to article research and development from using a chemical substance; (5) direct industry towards non-toxic chemicals '*Green Chemistry*', where industry by using such chemicals avoids the need to report data against a given chemical substance (Koch and Ashford, 2006; Wilson and Schwarzman, 2009; Tickner, et al, 2015; Tickner and Jacobs, 2016; Krimsky, 2017; Botos, Graham, Illés, 2018; Negev, et al, 2018; Sackmann, et al, 2018).

2.2.5.2 Global initiatives

Figure [2-5] describes the paradigm of: (1) industrial growth and evolving models of manufacturing; (2) the growth of registered chemical substances on the CAS database, and; (3) global initiatives and agreements to work towards removing the most hazardous and persistent chemicals, whilst maintaining economic growth. Table [2-2] describes the global initiatives and regulations in more depth.

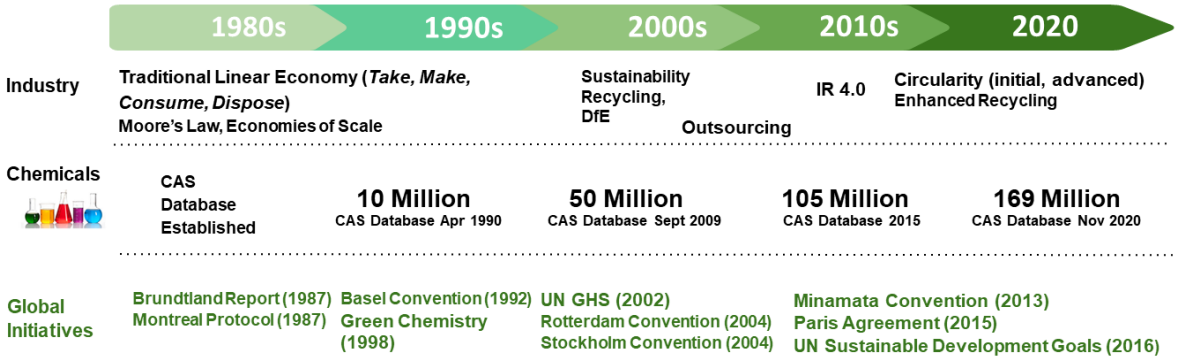


Figure 2-5: Changing landscapes

Table 2-2: Global initiatives

Year	Initiative / Regulation	Description	Source(s)
1987	Brundtland report.	• Identified the correlation between mass production and the rapid depletion of natural resources.	WCED, 1987.
1987	Montreal Protocol.	• Phasing out of Ozone Depleting Substances (ODS) substances which were known to cause damage to the Ozone layer.	UN, 2019a.
1988	Green Chemistry.	• The concept of using toxic-free chemicals.	Tickner, et al, 2015; Tickner and Jacobs, 2016.
1992	Rio Earth Summit.	• Sustainability treaty.	UN, 2019b.

Year	Initiative / Regulation	Description	Source(s)
1992	Basel Convention.	• Control transboundary movement of hazardous wastes.	Basel.int, 2019.
1997	Kyoto Protocol.	• Reduction in GHG emissions.	UN, 2019c.
2002	UN GHS standard.	• Uniform identification chemical substances to associated potential hazard(s).	UN, 2019d.
2004	Rotterdam Convention.	• Prior Informed Consent (PIC) process for certain hazardous chemicals and pesticides in international trade, where nations are obliged to inform other nations where specific highly hazardous chemical substances are identified.	Pic.int, 2019.
2004	Stockholm Convention.	• Eliminate or restrict the production and use of Persistent Organic Pollutants (POP) substances.	IPCS, 1995; Pic.int, 2019.
2005	EU Emissions Trading System (ETS).	• Reduction of GHG's in a cost-effective manner, where emissions are capped, and can be traded with other nations to reduce emissions via investment in clean low-carbon technologies in those countries	EC, 2020a.
2006	Strategic Approach to International Chemicals Management (SAICM).	• UNEP sponsored multi-stakeholder platform relating to chemicals management. SAICM has established a programme to develop Chemicals in Products (CiP) reporting, aimed at enabling wider industrial reporting of chemical substances in products, however much of the work has been of a basic exploratory nature only	SAICM, 2019a; SAICIM, 2019b.
2013	Minamata Convention.	• Reduce the use and release of Mercury and Mercury compounds.	Mecuryconvention.org, 2019.
2015	Paris Agreement.	• Further control of GHG emissions signatory nations pledged significant reductions in emissions by 2030.	IMF, 2015; UN, 2019e.
2016	UN Sustainable Development Goals (SDGs).	• Global adoption of sustainability initiatives	UN, 2020.

2.2.5.3 European regulations and initiatives

Within the EU, initiatives define the high-level strategies which can then be rolled out as either (b) directives where the member states agree a process to be adopted, which then requires local regulations to be enacted by the member states, EU Directives are not legally binding, but do have defined dates of application from which EU member states must implement their own local regulations, no later than 6 months prior to the date of application; (2) Regulations are an agreed legal framework and become law upon publication with a defined date of application to enable industry to develop applicable procedures. Table [2-3] describes key EU initiatives broken out as either (1) EU policies, or; (2) EU chemical regulations with applicability to the AD sector.

Table 2-3: EU Initiatives, Chemical Regulations and AD Impacts

Year	Initiative / Regulation	Type	Description	AD application?	Source(s)
2002, 2011.	EU Restriction of Hazardous Substances (RoHS).	Directive.	• Chemical substances banned outright in electronic articles unless an exemption for continued short term use is granted.	**Indirect** AD sector can be in-directly affected by restrictions placed on electronic articles.	EU, 2003; EC, 2011.
2006.	EU Registration, Evaluations, Authorisation, and restriction of CHemicals (REACH).	Regulation.	• Aims to protect human health and the environment by monitoring, controlling, and restricting the use of hazardous chemicals known as Substances of Very High Concern (SVHCs).	**Yes** Civil Aviation: in-scope. Defence: may be made exempt via local member state exemption provisions.	EC, 2006a.
2006.	EU Batteries and Waste Batteries and Accumulators.	Regulation.	• Requires identification of hazardous substances, labelling of batteries and sets recyclers targets for recycling content at a minimum of 50%.	**Yes** Civil Aviation and Defence sector consumes batteries in multiple use case scenarios.	EC, 2006b.
2008.	EU Classification, Labelling and Packaging (CLP).	Regulation.	• EU implementation of the UN GHS standard on labelling and packaging of chemical substances and mixtures. CLP requires applicable registration of substances and mixtures. • UN GHS also defines the structure for Safety Data Sheet (SDS) records detailing any hazardous substances contained with mixtures.	**Yes** Where AD organisations define their own formulations for example coatings, fuels, maintenance chemicals, etc.	EC, 2008a.
2009.	EU Ecodesign Framework.	Directive.	• Initially implemented as specific set of design requirements for eco labelling and power consumption requirements, for a specific set of article type groups, which impacted the AD sector in-directly.	**Indirect / Yes** Defines best practice requirements for the design of articles and reporting of eco related information.	EC, 2009a.
2009.	EU Ozone Depleting Substances (ODS).	Regulation.	• Implemented to monitor the use of chemical substances that generated harmful GHGs, pushing industry towards reporting current use, moving towards using alternative substances.	**Yes** ODS substances are likely to be found on older legacy products for example within a nacelles aero-engine surround.	EC, 2009b.
2012.	EU Waste Electronic and Electrical Equipment (WEEE).	Regulation.	• Sets out guidelines for the identification of chemical substances, labelling and disposal targets for electronic articles.	**Indirect** AD sector can be in-directly affected by requirements placed on electronic articles.	EC, 2012a

Year	Initiative / Regulation	Type	Description	AD application?	Source(s)
2012.	EU Treaty on the functioning of the EU.	Treaty.	• Article 191(2): defined 4 environmental principles when defining EU directives and regulatory actions: o Precautionary – allows regulatory action to be defined where risk certainty has not been fully established. o Prevention – prevention of environmental damage taking place (humans, animals, soil, water); o Rectification – prevention of pollution at its source. o Polluter pays – financial costs of rectification met by polluters.	**Yes** Defines widespread obligations for member states. Impacts the rules on identification of chemicals and applicable regulatory processing.	EU, 2012.
2012, 2014.	EU Biocidal Properties (BPR).	Regulation.	• Requires the identification of active ingredients in biocidal products which are used to protect products from harmful organisms. • Biocidal products cover preservatives, cleaners, disinfectants, etc. Products which have biocidal products applied to them are defined as 'treated articles'. • Under EU BPR, only specific active ingredients used in biocidal products from approved suppliers are allowed within the EU. • Treated articles which contain non-compliant active substances are banned by default.	**Yes** Within the AD sector this covers anything used to clean metals, fabrics, plastics.	EC, 2012b.
2014.	EU Fluorinated greenhouse gases.	Regulation.	• Control, monitoring, and reporting of F-Gas substances.	**Yes** F-Gas substances are likely to be found on AD articles.	EU, 2014a.
2014.	EU Public Procurement (PPD).	Directive.	• Defines a criterion for public authority expenditure, which includes a general criterion for sustainability.	**In-Direct** Sets out procedures for public authority procurement requirements.	EU, 2014b.
2014.	EU Non-Financial Reporting (NFRD).	Directive.	• Requirement for reporting data to appear on EU based legal entity annual reports, for organisations with greater than 500 employees, covers (i) environmental matters; (ii) employee rights; (iii) human rights; (iv) social matters; (v) anti-bribery and corruption; (vi) diversity of company boards.	**In-Direct** Impacts organisational policies and procedures.	EU, 2014c.

Year	Initiative / Regulation	Type	Description	AD application?	Source(s)
2017.	EU Conflict Minerals Reporting (CMR).	Regulation.	• EU responsible mineral reporting requiring identification of the source of supply for gold, tin, tantalum, and tungsten.	**Yes** Identify which article consume the minerals then identify source of supply.	EC, 2020g.
2018.	EU Waste Framework (WFD).	Directive.	• Originally implemented to define waste recycling targets, procedures for managing waste. • Updated in 2018, to implement chemical reporting data into a new central EU database to support recycling industry in identification of any hazardous chemicals in EOL articles.	**Yes** Civil Aviation: in-scope. Defence: may be made exempt via local member state exemption provisions.	EC, 2018b.
2018.	EU Packaging and packaging waste.	Directive.	• Defines rules on design of packaging, rules on packaging including waste management.	**Indirect** Applicable when AD articles are shipped using standard cardboard, wooden containers.	EU, 2018a.
2018.	EU Plastics.	Strategy.	• High-level strategy to increase use of plastic materials to make them more recyclable with penalties for use of virgin plastic materials versus using recycled secondary raw materials.	**Yes** Plastic materials used widely, impacts policies on procurement of plastic materials.	EU, 2018b.
2019.	EU Persistent Organic Pollutants (POP) recast.	Regulation.	• EU specific regulation implementing globally agreed POPs restrictions and exemptions under Montreal Protocol.	**Yes** POP substances may appear in AD articles.	EU, 2019.
2019.	Nanomaterials.	Added to EU REACH.	• Nanomaterials were originally considered out of scope for EU REACH, primarily as they were deemed to be too complex in nature due to differing sizes, primarily altering the DNA of existing substances. • EU REACH annexes updated in 2019 to include review of nanomaterials.	**Yes** Nanomaterials such as Graphene are widely used within AD, the new EU REACH reporting requirements for nanomaterials may result in them being added to the reportable chemical substance lists under EU REACH.	EUON, 2019.
2019.	EU Green Deal.	Strategy.	• Long-term strategy for implementing increased movement towards sustainability and the circular economy.	**Yes** High-level and targeted actions will impact the AD sector.	EC, 2020b; EC, 2020c.
2020.	EU Chemical Sustainability.	Strategy.	• Specific roadmap defining (i) increased reporting of hazardous chemicals across multiple chemical regulations; (ii) potential taxation; (iii) increased enforcement, and: (iv) specific strategies for industrial sectors.		EC, 2019e.

Year	Initiative / Regulation	Type	Description	AD application?	Source(s)
2020.	EU Circular Economy Action Plan (CEAP).	Strategy.	• Lower-level action plan flowing from the green deal.		EC, 2020d; EC, 2020e.
2020.	EU Critical Raw Materials (CRM).	List.	• Defined list of materials deemed scarce but critical to EU industry. The main purpose of the list is to o Identify materials and sources of supply. o Prioritize recycling activities.	**Yes** AD sector uses several CRMs.	RMIS, 2020.

The following sections discuss three key pieces of EU regulations / directives that are likely to impact the AD sector: (1) EU REACH regulation, and (2) the EU Waste Framework Directive and (3) EU Market Surveillance and Compliance of Products Regulation.

2.2.5.4 EU REACH Regulation

The EU REACH regulation was originally authored as a discussion paper in 2001, during a period in which the traditional linear economic model of taking natural resources, producing articles which were disposed of into waste streams, little regard was made in the original EU REACH legal text towards sustainability and recycling activities (EC, 2001). The EU REACH regulation is the core EU chemical regulation which established a regulatory framework for the identification, reporting and control of SVHCs (EC, 2006a). A high-level summary of the EU REACH regulation is shown in Table [2-4]. A fundamental feature of EU REACH is the concept of '*no-data no-access*' principle which results in manufacturers and importers needing to provide data, if no provided, then articles can be restricted from being placed onto the EU marketplace.

Table 2-4: High-Level overview of the EU REACH regulation

Element	Description
COmmunity Rolling Action Plan (CoRAP).	• Structured member state review process for assessing chemical substances. • Review processes can take several years entailing extensive data collection, review and analysis of scientific evidence and socio-economic impact data as chemicals are assessed for further action(s).
European CHemicals Agency (ECHA).	• Central body established to manage the identification, evaluation, and control of hazardous substances within the EU.
Register substances: Article 7(2).	• Legal requirement for manufacturers and importers into EU to register chemical substances being consumed over 1T per annum, either on their own, within mixtures, materials, and articles. • This information is used to identify registered substances, which forms the basis for identifying a road map for substance reviews.
Report substances: Article 33.	• Article manufacturers are obliged to provide data known as Article 33 declarations, to downstream users, covering professional users, recyclers, and end consumers, where substances from the ECHA candidate list of substances appear >0.1% w/w per article. • Once a new SVHC appears on ECHA candidate list, article manufacturers / importers have up to 6 months in which to identify and report. • Under Article 33, a consumer of can request data from article manufacturers / importers, who must then provision the data within 45 days.
EU REACH Candidate list of substances of very high concern for Authorisation.	• Initial watch list of substances. Articles containing SVHCs > 01% w/w threshold level appearing on an article require EU REACH Article 33 materials declarations to be provisioned by article manufacturers. • Updated twice a year. Applies to all articles manufactured and imported into the EU.
EU REACH Authorisation list of substances (Annex XIV).	• SVHC substances identified against this list require approval in order to be used to produce articles, applies to EU based manufacturers (not importers), the key focus being to identify a date by which manufacturers should have applied for an authorisation, followed by a date from which a substance may be further controlled. Updated annually.

Element	Description
EU REACH Restricted list of substances (Annex XVII).	• List of the SVHC substances considered to be the most hazardous, which are then either banned outright or for a specific use case only, applies to all articles manufacturer and imported into the EU. Updated annually.
Once An Article Always an Article.	• Formal legal ruling by the European Court of Justice (ECJ), identified the need for industry to provide an Article 33 declaration to the lowest level component within a finished article that contains an SVHC substance (ECJ, 2015).

Several studies on the effectiveness of the EU REACH regulation have been undertaken, as shown in Table [2-5]. The studies show that there is a significant resource, time and cost burden placed on industry to meet the EU REACH reporting obligations. The running theme throughout the studies is lack of clarity over understanding of reporting obligations and the quality of data being transmitted to both the applicable ECHA systems and across a supply chain. EU Member State Competent Authorities (MSCAs) were established under the EU REACH to manage the compliance and enforcement activities at a member state level. Article 126 of EU REACH (EC, 2006a), allows EU MSCAs to individually set their own provisions and penalties as shown in Figure [2-6], the average fines and penalties for non-compliance under the EU REACH ranged from 50k euros and 1M euros, per article, which can be applied at each member state level.

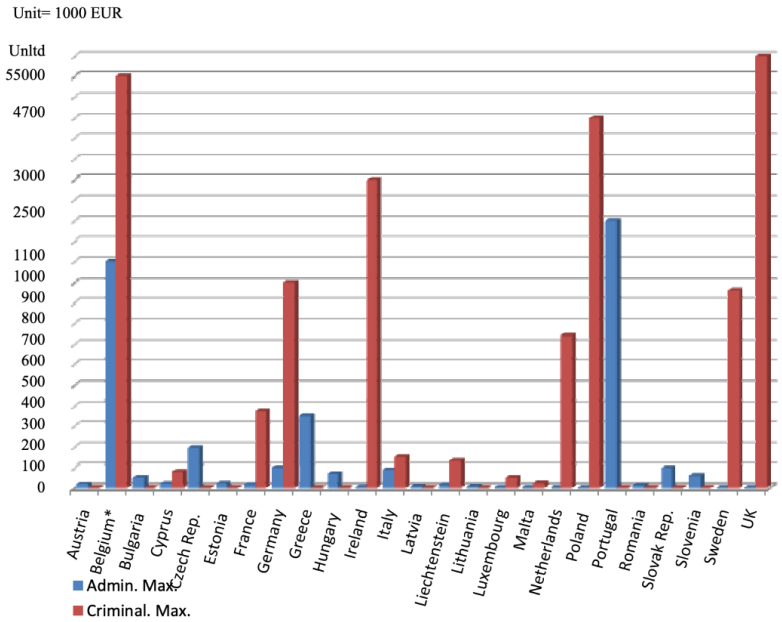


Figure 2-6: Fines (legal and administrative) that may be imposed under EU REACH
Source: Adapted from CIRS, 2015.

Table 2-5: Review of studies on EU REACH regulation impacts

Year	Conducted by	Study name	Description	Comments	Source(s)
2013.	European Commission.	Commission report in accordance with Article 117(4) of EU REACH and Article 46(2) of EU CLP.	• EU REACH and EU CLP regulations require regular reviews of how the efficacy of the regulation. First larger scale fitness checks for both EU REACH and EU CLP regulations. • Conducted over the first five years from date of application of the EU REACH regulation covering 2007 to 2012. • Estimated that over a 30-year period, the benefits of EU REACH in terms of reducing the use of hazardous substances leading to an estimated €50 billion benefit in savings to public health care systems.	Identified: (1) potential duplicated reporting between EU REACH and other regulations, and; (2) the need for closer collaboration ECHA, the commission, EU member states and industry to ensure compliance and data consistency.	EC, 2013a.
2014.	ECHA.	Evaluation under REACH Progress Report.	• ECHA interpretation document from 2013 initial fitness check of the EU REACH regulation. • Identified data quality and data consistency issues with data submitted in as part of the initial 2010 deadline for registration of all chemical substances consumed at >100 Tonne per annum threshold band. This was the first major milestone for all industries within the EU to report information to ECHA.	Identified data quality and data consistency issues with data submitted, made recommendations for industry to regularly review submitted data. The data issues were attributable to: (1) industry needing to establish internal systems and processes to analyse data, prior to making the correct data submissions, whilst; (2) during the same period the EU REACH legal text and ECHA development of reporting systems also evolved.	ECHA, 2014.
2016.	European Commission.	Cumulative Cost Assessment for the EU Chemical Industry.	• Analysed data between 2004-2014. Extensive cost impact assessment examining all cost burdens for the EU Chemical industries because of EU legislation. • Annual cost of €9.5 billion to the EU Chemicals sector, where (1) 75% of this cost was directly attributable to EU REACH, CLP, BPR and Plant Protection Product (PPPs) regulations; (2). 20% of 75% cost was attributable to financial obligations to charges, fees, registrations fees.	Identified the direct costs to the chemicals industry to report against chemical regulations. Whilst this study was specific to the EU chemicals sector, the costs and data management issues extrapolate across the supply chain as the chemicals are then transformed into mixtures, materials, and articles.	EC, 2016.
2017.	European Commission.	Commission staff working document laying down rules and	• Analysed compliant and non-compliant articles entering the EU marketplace.	Despite the legal obligations to provision data on SVHCs within articles, non-compliant articles entering the EU marketplace were estimated at €342 Million per annum.	EC, 2017c.

Year	Conducted by	Study name	Description	Comments	Source(s)
		procedures for compliance.			
2018.	European Commission.	Commission General Report on the operation of REACH and review of certain elements.	• Second large-scale fitness check of the EU REACH regulation. Called for an alignment of chemicals management and UN SDGs. • Identified a lack of updates taking place to original initial EU REACH substance registrations only 25% of 65K submitted dossiers were being maintained. • The cost to industry for data collection and mandatory data sharing was estimated for EU REACH substance registrations at between EUR 2.3 billion to 2.6 billion. 35% higher than original forecasts. • The costs of maintaining the activities undertaken by ECHA was estimated to be EUR 757 million between 2007-16.	Important study as it showed the need for supply chain actors to improve data collection and provision because of EU REACH reporting obligations. Divergences between EU Member interpretations of 0.1% threshold value for a given article, under EU REACH article 7(2) and Article 33 reporting obligations. This influenced changes in the EU Market Surveillance Regulation.	EC, 2018a.
2018.	AskREACH!	Many companies not informed about SVHCs in their articles.	• Surveyed 174 organisations identifying: (1) on average 84 monthly EU REACH Article 33 requests were being request; (2) 50% of the companies stated they did not have the required information to respond to EU REACH Article 33 requests within 45 days from a receipt; (3) 47% of companies felt they had sufficient data to respond to Article 33 requests; (4) 43% of the companies had no IT solutions to collect data; (5) from the 57% of companies which stated that they had IT tools, 25% stated they still used MS-Excel based tools to collate supply chain chemical substance information.	Identified companies were receiving Article 33 requests, however a large proportion of companies lacked awareness of the data that needs to be collated, analysed, and reported in a consistent manner to meet reporting obligations.	AskREACH!, 2018.
2019.	ECHA.	Forum Pilot Project Substances in Articles.	• Analysed 682 articles from 405 companies from 15 EU Member States, between 2017 and 2018. The study targeted consumer articles. • 84 articles (12%) contained reportable SVHCs. • EU REACH Article 7(2) reporting obligations were met by all 682 articles examined.	Identified the reporting obligations under Articles 7(2) and 33 reporting impose significant burdens on industry. Issues persist as identified in earlier studies relating to duty holders not fully understanding their reporting	ECHA, 2019d; EC, 2018b.

Year	Conducted by	Study name	Description	Comments	Source(s)
			• EU REACH Article 33 reporting: from the 84 articles identified as containing SVHC substances, 75 articles (89%) were identified as being non-compliant to EU REACH Article 33 legal obligations. • *'This shows that there is a big gap in communication throughout the supply chain and many of the suppliers are outside of the EU'.*	obligations and the flow of data across a supply chain. The outcomes from this study influenced the ECHA SCIP database defined duty holder roles and responsibilities design.	

2.2.5.5 EU Waste framework directive

A fundamental objective of the EU REACH regulation was to ensure via the Article 7(2) and Article 33 reporting obligations to enable data to flow consistently across all actors within a supply chain. The presumption across the legal text was that the data flow of information would persist as articles entered EOL states, with the data then finally arriving to waste stream operator. Table [2-5] identified the continued lack of clarity over roles and reporting obligations for supply chain actors, very little data was flowing down to waste stream operators, who needed to identify chemicals of concern in articles they receipted which due to EOL waste streams, could be several years after the article was originally sold. The author as part of this research study participated in several EU circular economy stakeholder forum events and conferences between 2018 and 2020. Outcomes from the 2018 EU circular economy stakeholder conference (EC, 2018c) saw strong feedback comments from waste stream operators related to the lack of data made available to them from article manufacturers and importers, due to lack of shared data systems, this was seen as hindering recycling activities. This feedback, in conjunction with the EU REACH review studies conducted in Table [2-5] defined the need for driving new reporting obligations. The updated EU Waste Framework Directive (WFD) 2018/851 (EC, 2018b) established under Article 9(2) a mandate for ECHA to create and maintain a new central European database which has come to be known as the ECHA Substances of Concern In articles as such or in complex objects (Products) (SCIP) database (ECHA, 2021); and (2) industry at various duty holder levels must now provision data into the ECHA SCIP database, known as SCIP article notifications based on previously collected EU REACH Article 33 data collected from the supply chain with additional data elements. Table [2-6] the differences between EU REACH and the ECHA SCIP database.

Table 2-6: Comparison between EU REACH and ECHA SCIP database notifications

Context	**EU REACH Article Notifications**	**ECHA SCIP Notifications**	**Description**
Use case.	Reporting the presence of SVHCs on all new articles.	Act as a central European database for waste stream operators to utilise. Data can be accessed by the public and NGOs via a public portal.	EU REACH established the EU chemicals management framework.EU WFD established a waste hierarchy framework for managing waste, setting targets for EU Member States and penalties for non-compliance.
List of reportable substances.	EU REACH Candidate List of substances of very high concern for Authorisation.		Initial watchlist of SVHC substances where legal reporting obligations apply in both EU REACH and ECHA SCIP notifications.

Context	EU REACH Article Notifications	ECHA SCIP Notifications	Description
ECHA role.	Store and process Article 7(2) notifications. Article 33 declarations generated and distributed by supply chain actors.	(1) duty holders and reporting obligations to the ECHA SCIP database; (2) format and structure of data to be reported.	ECHA was given a pivotal role in the establishment of the SCIP database.
Duty Holders.	Importers / Manufacturers of chemical substances, mixtures, and materials to flow data up to the article assemblers. Article assemblers to generate their own article 33 declarations. Distributors relied on data being provisioned by Importers / Manufacturers and Assemblers	(1) Importers / Manufacturers of lower-level articles making initial SCIP notifications; (2) Assemblers of complex articles using SCIP notification data from (1), generating SCIP numbers for their complex articles, and (3) Distributors making notifications as articles move across as supply chain, unchanged	EU REACH studies showed identified a lack of data transmission under EU REACH as supply chain actor roles not being clearly defined in the legal text. ECHA SCIP database, duty holder obligations were defined against known sources of data discrepancies (from EU REACH review process), requiring supply chain actors to provision data where applicable. This was the first legislation that implemented a requirement for distributors to report data across the distribution chain for articles.
Reporting Obligations.	Article 7(2): Identification of SVHC use on its own, within mixtures, materials, and articles >1 Tonne per annum. Article 33: reporting at lowest article level. Many organisations maintain reporting at the article as received not at the ECJ ruling article level.	Article 9(2): Identification of additional datapoints beyond just the name of the SVHC. Data must be reported in a BOM like structure identifying: (1) article name / code; (2) tariff code; (3) production in the EU; (4) safe use data; (5) SVHC data; (6) identification of SVHC form (mixture/material level)	Whilst EU REACH Article 33 level reporting amended by the ECJ ruling to report at lowest article level in 2016. EU REACH article 33 declarations at a minimum identified article name and SVHC substance data. ECHA SCIP reporting requires obtaining additional data from articles as identified as containing SVHC substances from standard EU REACH reporting requests.

Source: EC, 2006a; ECJ, 2015; EC, 2018b; ECHA, 2019e; EC, 2019f, ECHA, 2020a; ECHA, 2021b.

A lot of concern was expressed by industry regarding the additional reporting obligations being imposed by having to report into the ECHA SCIP database. The author has represented both (1) the electronics sector via IPC trade association, (2) the medical devices sector via MedTech Europe, in trade association meetings between manufacturers and waste operators. Additionally, the Author has been involved in the design of the ECHA SCIP database as a member of the ECHA SCIP IT user group since September 2019. Reporting to the ECHA SCIP despite fears expressed by industry is pivotal to further development of the circular

economy activities. In extending the reporting requirements under EU REACH to ECHA SCIP database reporting, ECHA has established the biggest article database in the world, as of mid-March 2021, over 3,600 legal entities have registered accounts with over 10 million SCIP article notifications have been submitted for articles containing SVHC substances (ECHA, 2021b). Reporting into the ECHA SCIP database has imposed significant burdens on industry to ensure the correct SVHC data is provisioned by the appropriate supply chain actors. ECHA's application of the ECJ ruling (ECJ, 2015), clearly identified discrepancies between industry assumed current state EU REACH data collection and downstream Article 33 communication requirements versus the correct current legal interpretation as updated by the ECJ ruling, as implemented by ECHA. The author, through work related activities engaged with over 150 global organisations, from multiple industry sectors during 2020, in 40% of cases, split between organisations located within the EU and non-EU, the way current state EU REACH related data was being collected was based on reporting against the article as sold and received at the finished article level and not at the constituent article within a complex article level. Faced with ECHA SCIP database reporting requirements necessitating the need to collect and analyse data at the once an article level, has caused significant concern. The additional duty holder roles have levelled the reporting obligations for all supply chain actors (1) importers located in the EU, who utilise non-EU supply chains now need to ensure a similar level to EU located manufacturers and assemblers; (2) distributors whilst having a reporting obligation under EU REACH, often referred to manufacturer websites or technical documentation, which was not typically refreshed with a regular cadence within updated information, under ECHA SCIP database reporting requirements, distributors must identify the flow of articles containing SVHCs across the distribution chain, by making SCIP article notifications at a per legal entity, per EU Member State level, which is a significant change, to previous current state practices.

2.2.5.6 EU Market surveillance regulation

The EU Market Surveillance and Compliance of Products Regulation (EC, 2019b) was implemented to support the activities of all EU-27 MSCAs: (1) by establishing clear guidelines for interpreting and assessing the legal text of all existing 69 EU product regulations. This was undertaken because of the studies in Table [2-5] identifying inconsistencies in interpretation of regulatory texts, which written in European business English, versus localised translations across all EU-27 MSCAs; (2) all EU-27 MSCAs to define current state inspection, test and enforcement activities, from which best practice methods and roadmap strategies for all EU-27 MSCAs will evolve, ultimately resulting in

harmonised inspection, test and enforcement actions; (3) undertaking new detailed training schemes across all EU-27 MSCAs to understand the required inspection, test and enforcement actions; (4) under Articles 4(1), Article 44 defines the requirement for economic operators to provision data to MSCAs when requested. Economic operators are anyone offering articles and services for any type of exchange, covering freely distributed articles; (5) in order to place articles onto the EU marketplace, the regulations require an EU-27 member state located representative to be defined for organisations placing articles onto the EU marketplace; (6) establish a new back-end IT system to enable EU MSCAs to share information on suspected non-compliant products, potentially integrating with the ECHA SCIP database. This IT system is being implemented in several phases, the first phase to have integrated data sharing system was specific to import / export system, this was implemented on 1st January 2021, further stages will see enhanced platforms being managed by the EC; (7) updates to the legal texts of all 69 regulations examined in to clearly state the roles and tasks of the EU-27 MSCAs, such that industry clearly understands obligations to report data to EU-27 MSCAs; (8) enhanced enforcement powers that enable EU-27 MSCAs to (a) carry out unannounced site inspections; (b) carry out physical product checks in ports of entry; (c) restrict products from the EU marketplace; (d) order recalls; (e) place actions on economic operators to bring non-compliant articles into a compliant status; (f) to order companies to remove non-compliant articles from online stores, regardless of the physical location for a company; (g) ban articles and company websites from being displayed within the EU; (h) to recover the cost of identifying and testing suspected products once they have been identified as being non-compliant.

2.2.5.7 Other regulations and initiatives which could potentially impact the AD sector

Table [2-7] identifies additional other global regulations which have been assessed in terms of impacts to the global AD sector.

Table 2-7: Other initiatives and regulations that may impact the AD sector

Year	Name	Type	Region	Description	AD application?	Source(s)
1976.	Toxic Substances Control Act (TSCA).	Regulation.	US.	• One of the first chemical regulations implemented. Established framework to review and classify chemical substances. • The traditional focus of TSCA was on chemicals, however a 2016 update known as Section 6(h) introduced a new reporting requirement to be implemented in September 2021, for substances in articles.	**Yes** Applicable to all chemicals in the US.	TSCA Wiki, 2020.
1986.	Safe Drinking Water and Toxic Enforcement Act.	Regulation.	US.	• Commonly known as California Proposition 65. Requires manufacturers to identify and label products which contain known hazardous substances known to cause cancers or birth defects, failing to disclose information can lead to manufacturers facing litigation actions where labels are incorrectly placed on articles.	**Yes** Applicable to all products manufactured, distributed, and sold with California.	OEHHA, 2020.
1999.	Canadian Environmental Protection Act (CEPA).	Regulation.	Canada.	• Several substance lists requiring different actions to monitor and control, identified over 23,000 chemical substances.	**Yes** Dependent on substance list, different actions will apply.	Government of Canada, 2019.
1999.	Environmental Enforcement Act.	Regulation.	Canada.	• Works in conjunction with CEPA enabling enforcement penalties which can range from $5,000 to $6 Million.	**Yes** Works in conjunction with CEPA.	
2008.	The Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles.	Regulation.	South Korea.	• South Korea variant of EU RoHS.	**Indirect** See EU RoHS, same substances, but different product group types and exemption approvals will apply.	RoHSGuide, 2020.
2010.	Dodd-Frank Wall Street Reform and Consumer Protection Act, section 1502.	Regulation.	US.	• Commonly known as US Conflict Minerals Reporting (CMR). • Requires identification of mining sources for Tin, Tungsten, Tantalum and Gold.	**Yes** Applicable to all US listed companies, reported on financial accounts. Impacts non-US companies as data	SEC, 2012.

Year	Name	Type	Region	Description	AD application?	Source(s)
				• The key aim of this regulation was to limit the amount of enforced child labour used in mining operations in the DRC. • The reporting for this regulation is shown in financial reports for US companies.	must be reported by US based AD customers.	
2013.	Act on the Registration and Evaluation of Chemicals.	Regulation.	South Korea.	• Commonly known as K-REACH. • Originally implemented in 2013, then updated in 2015, and 2019. • Aligned to the regulatory framework as implemented in EU REACH.	**Yes** Like EU REACH in terms of chemical substance identification and reporting obligations.	CIRS, 2019.
2015, 2020.	NAS 411.	Reporting requirement.	US.	• US military reportable list of substances organised as (1) tracked; (2) restricted and (3) prohibited.	**Yes** Applicable to all articles and services sold to the US military agencies.	AIA, 2016.
2016.	The Frank R. Lautenberg Chemical Safety for the 21st Century Act.	Regulation.	US.	• Amended TSCA to include a mandate for the US EPA to evaluate all chemicals, with enhanced supply chain data reporting with risk-based assessments and greater public transparency. • Defined reporting criteria for Section 6(h) and new inspection powers at customs to enable inspection of articles entering the US.	**Yes** Impacts scope of chemical substances under TSCA and additional supply chain reporting data provisions.	US EPA, 2019.
2016.	CU TR 037/2016.	Regulation.	Russian, Kazakhstan, Uzbekistan, Turkmenistan, Georgia, Kyrgyzstan, Tajikistan.	• Eurasian RoHS.	**Indirect** See EU RoHS, same substances, but different product group types and exemption approvals will apply.	RoHSGuide, 2020.
2017.	Cabinet Decision No. 10/2017.	Regulation.	UAE.	• UAE RoHS.		
2017.	KKDIK.	Regulation.	Turkey.	• Turkey implementation of EU REACH type regulation.	**Yes** Like EU REACH in terms of chemical substance	RoHSGuide, 2020.

Year	Name	Type	Region	Description	AD application?	Source(s)
					identification and reporting obligations.	
2018.	United States, Mexico, Canada Agreement (USMCA).	Trade agreement.	US, Mexico, Canada.	• Replaced North American Free Trade Agreement (NAFTA), introduces specific clauses which requires monitoring of (a) emissions; (b) pollutants; (c) environmental contaminants; (d) control of environmentally hazardous or toxic chemicals, substances, materials, or waste with information being provided by industry and monitored by authorities. The identification and control of chemical substances under USMCA requires the US, Mexico, and Canada to establish applicable regulations to enact and enforce, however, it also presents industry with new reporting requirements which are theoretically as significant as the original EU REACH implementation project.	**Yes** USMCA applies to all articles that are sold, shipped, or transported between US, Canada, and Mexico.	USTR.gov, 2019.
2019.	MEP 7.	Regulation.	China.	• Evolving chemical regulation. Originally drafted by the MEP, order 7, in 2010, then updated in 2015, 2017 and 2019.	**Yes** Applies to chemical substances, mixtures, materials, and articles.	ChemicalWatch, 2019.
2020.	Electronic Product Environment Assessment Tool (EPEAT).	Regulation.	US.	• The is a ranking tool used by major global electronic brands to showcase their environmental credentials, originally implemented specifically for energy ratings, the EPEAT standards have evolved to include EU RoHS, EU REACH candidate list of substances reporting.	**Indirect** Impacts reporting for servers, computers, monitors which are likely to be used by AD sector**.**	EPEAT, 2020.

2.2.5.8 Quantifying the impact of chemical regulations upon industry

Within the EU, statistics highlighted the costs for regulatory compliance on industry for EU regulations between 2004 and 2014, amounted to €9.5 billion per year, which represented nearly 2% of annual turnover (EC, 2016). The costs of collecting data and ensuring compliance to environmental regulations, are seen by industry as: (1) increasing costs, where supply chain compliance reporting is seen as a non-value adding activity which is does not enhance an organisation's ability to maintain its competitiveness (Palmer, et. al, 1995; Poelhekke and van de Ploeg, 2015); (2) organisations may switch manufacturing to nations with cheaper costs of manufacturing and less stringent environmental controls (Copeland and Taylor, 2004).

2.2.6 Examination of the global AD sector

This section presents a systematic review of the global AD sector, with a specific focus on the design and manufacture of aircraft. Extensive elements of this section are based on the authors experience within AD sector managing manufacturing environments, developing engineering design systems, and engaging with several AD organisations in the development of IPC-1754 to identify current state supply chain chemical substance reporting activities. The review underpins the development of the research question and design of the conceptual framework.

2.2.6.1 Civil Aviation sector

The Civil aviation sector covers aircraft used for transporting passengers as well as the movement of goods. The sector has seen increasing numbers of passengers and articles being transported, leading to a strong demand for new aircraft (IATA, 2019). Airline operator profitability in 2018, stood at $812 billion annual revenues with net profits estimated at $30 billion (IATA, 2019), profitability of airline operators has been gradually declining in recent years primarily due to rising costs attributed to fuel and CO2 emission charges. The underlying demand for new aircraft is based not entirely on profitability of the airline operators, indeed the highest demand for civil aviation articles comes from Lessors, where leasing companies purchase new aircraft and lease them to airline operators over several years.

2.2.6.2 Defence Aviation sector

Table [2-8] presents a high-level summary of the Defence aviation sector. A cumulative revenue figure for the Defence sector spending of $1,822 billion, in 2018, was derived from data from the top 15 national and regional defence agencies (Wikipedia, 2019).

Table 2-8: Defence Aviation Sector Summary

Product category	**Subcategories**
Aircraft systems	• Civil aircraft where internal systems such as seating, air conditioning, lighting systems are removed and adapted for defence uses. • Aircraft specifically designed for defence uses. • All ancillary equipment that connects to aircrafts, enabling repair and maintenance activities to be performed.
Land and naval systems	• Motor vehicles, shipping vessels, radar systems, missile systems, drones, communications systems.
Space systems	• Rocket systems, spaceships, communication systems.
Telecommunication systems	• Remote monitoring systems, cyber security systems, satellite communications systems.

Investment and expenditure within the defence sector aligns less on global economic conditions, moreover on rising geopolitical tensions such as: (1) NATO increasing expenditure to defend against both physical and technological from Russia; (2) India, China, Japan, Saudi Arabia increasing expenditure against presumed threats from neighbouring nations; (3) advancing technologies resulting in increased expenditure such as cyber defence, satellite communications, etc.

2.2.6.3 Determining the mean number of articles on an aircraft

Using publicly available data over 150 types of aircraft manufactured between 1957 and 2019 were examined in Appendix One. Table [2-9] depicts finished articles on an aircraft, which can consist of several times the displayed amount in terms of individual components which make up the finished articles, for example semi-components, components, semi-finished article numbers or indeed separate article identifiers to denote different machining processes undertaken against a Work In Progress (WIP) state article number throughout its manufacturing lifecycle state(s).

Table 2-9: Average aircraft data (cost $, size, range and articles)

Sector	**Type of aircraft**	**Average cost (2019 $ in Million)**	**Seats (min)**	**Seats (max)**	**Range (km)**	**Length (m)**	**Articles (min)**	**Articles (max)**
Defence	Turboprop and Jet engine powered aircraft only.	184.89	7	55	5,067	34.37		
Civil	Freight	340.34	3	69	5,229	52.35		3,100,000

Sector	Type of aircraft	Average cost (2019 $ in Million)	Seats (min)	Seats (max)	Range (km)	Length (m)	Articles (min)	Articles (max)
	Business / corporate	60.88	28	40	9,926	32.19		
	Regional	48.60	81	90	3,234	29.49		
	Narrow body	96.53	152	197	5,067	38.57	416,666	636,363
	Widebody	432.34	294	432	11,079	66.73	1,200,000	3,431,579

2.2.6.4 Complex AD supply chains

As industry has migrated towards highly integrated and complex supply chains, dispersed over global geographies, has resulted in heightened risks from supply chain disruptions, where a domino effect can occur as a result of a disruption impacting a lower tier supplier which flows to higher supply chain tiers (Yan, et al., 2015; Christopher, 2016). Supply chain disruptions are defined as events that impact the movement of goods or services along a supply chain (Craighead, et al., 2007). Supply chain disruption can occur from: (1) increasing costs for articles; (2) declining sales (Park, Min, Min 2016); (3) service failures for example Boeing 737 Max aircraft grounded to in-life product failures (USA Today, 2019) which has impacted the global AD supply chain; (4) natural disasters which in recent years have increased due to climate change; (5) regional conflicts; (6) international security concerns heightened by climate change where it has been recognized that climate change is seen as 'threat multiplier' (UN, 2019k); (7) Lancet, 2009 identified climate change as being the biggest threat to global health in the 21st century, opening a greater divide between advanced and emerging economies; (8) increasing trade conflicts between different regions such as US-China and US-EU tariff charge increases impacting a wide range of industry sectors (Reuters, 2019; FT, 2020a); (9) regulations that impact industry; (10) market instability such as financial instabilities, changing demands for articles, increasingly competitive environments where new entrants displace the existing status-quo; (11) outbreaks of viruses for example the SARS outbreak in China in 2003, caused less global supply chain disruption, due to limited global integration with Chinese manufacturing, however the recent Covid-19 pandemic has caused a much bigger impact to global supply chains.

2.2.6.5 AD article definitions

Figure [2-7] depicts how chemical substances are identified within AD articles based on a geometry drawing depicting the 'fit, form and function' of an AD article, by a design engineer which references materials engineer definitions in the form of: (1) material

specifications that reference the chemical substances, mixtures and materials which appear on the finished state AD article, and; (2) process specifications that reference the chemical substance, mixtures and materials that are used in the manufacturing process to produce the AD article, but do not appear on the finished AD article.

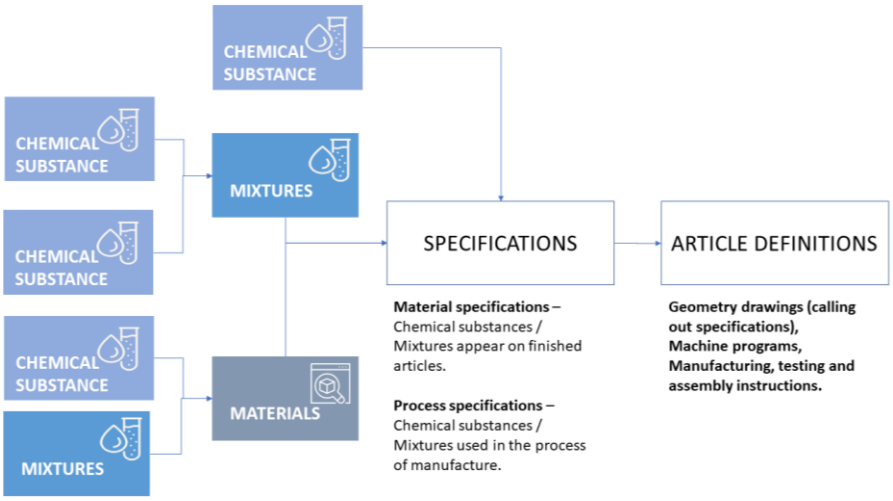


Figure 2-7: Chemical substances, specifications and article definitions

2.2.6.6 Bill of Materials (BOM)

A BOM can be described as the master configuration management structure of a single article or a complex article consisting of multiple lower-level articles. Engineering configuration management systems such as Product Data Management (PDM) and Product Lifecycle Management (PLM) store and manage article and engineering design related BOM data. PDM/PLM systems through a series of article lifecycle states and workflows including additional technical and release review boards, manage the release of engineering design data to other internal systems such as Enterprise Resource Planning (ERP) systems to schedule the delivery of the defined articles either internally or sourced from the supply chain, subject to customer demand based on sales orders. Typical article lifecycle states identified within PDM / PLM systems are: (1) WIP: the initial article lifecycle state, where an article is conceptualised with referenced specification; (2) Pre-Release: the article design becomes more formalised and is subject to initial review boards, prior to initial orders being placed for the chemical substances, mixtures and materials defined in the applicable reference specifications, at this state the article will be a prototype state where test articles may be manufactured and tested; (3) Released: the article is assumed to be in a production release state, additional scrutiny and review boards take place, prior to confirmation that the article can now be manufactured internally or sourced from the supply chain. There are several different BOM structure names and types used to denote the data contained within a

given BOM structure, which are used beyond the actual lifecycle state. Figure [2-8] depicts the commonly identified BOM types which may exist within a typical AD organisation.

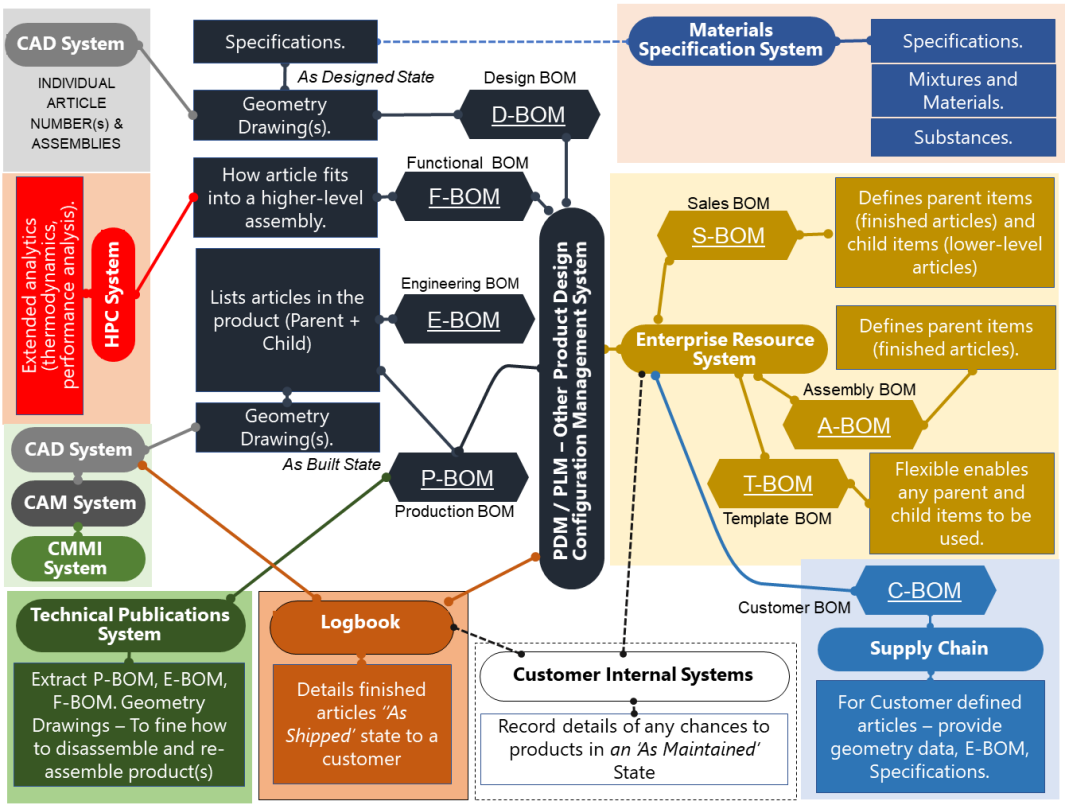


Figure 2-8: Examples of different BOM types used within AD sector companies

Table [2-10] expands on Figure [2-8] by defining the use and context of the different BOM types.

Table 2-10: Example BOM types within an AD organisation

BOM #	**Role**	**Description**	**CAD (geometry drawings)**	**CAM (machining programs)**	**Materials (specifications)**	**PDM/PLM (configuration data)**	**CMMI (inspection tasks)**	**ERP (schedule resources)**	**HPC (modelling)**
S-BOM (Sales BOM)	Defines articles placed on order by a customer.	Shows a fully exploded parent / child article level BOM.				Yes		Yes	
A-BOM (Assembly BOM)		Shows at the finished assembly only level BOM.						Yes	
T-BOM (Template BOM)		Flexible BOM, generated as required.						Yes	
D-BOM (Design BOM)	Defines geometry, and specifications.	Single article / complex article structure(s).	Yes		Yes	Yes			
E-BOM (Engineering BOM)	Defines how an article is manufactured and assembled.	Forms the basis for detailed machining, testing, and inspection as per the article fit, form and function requirements.	Yes	Yes	Yes	Yes	Yes	Yes	
F-BOM (Functional BOM)	Defines functional role of single article / complex article.	High Performance Computing (HPC) analytics testing thermodynamics and performance.	Yes		Yes	Yes			Yes
P-BOM (Production BOM)	Defines production state single article / complex article.	Two distinct states: (1) *'As Built'* as originally manufactured; (2) *'As Shipped'* where changes to a specific article may have been undertaken (design alterations / fixes / etc.)	Yes	Yes	Yes	Yes	Yes	Yes	
C-BOM (Customer BOM)	Customer defined BOM.	Customer specific article / article design requirements.	Yes	Yes	Yes	Yes	Yes	Yes	

2.2.6.7 Global AD sector pre Covid-19 pandemic

Table [2-11] presents a summary of the size of the AD sector, prior to the outbreak of the Covid-19 pandemic, a summary of the AD sector.

Table 2-11: Scale of global AD sector pre Covid-19 pandemic

Year	Region	Element / Statistic	Source(s)
2015	EU.	• AD sector revenue €222 Billion.	EACP-EURSME, 2018.
2017	Global.	• Revenue of top global 100 AD companies estimated $685 Billion. • Direct employees estimated 1.9 Million with 60% of companies located in the US.	Deloitte, 2018.
2018	USA.	• AD sector revenue $929 Billion. • Direct employees estimated 881,000, Indirect supply chain employees estimated 1.6 Million.	AIA, 2019.
2018	Global.	• Examination of annual accounts from 80 of the top 100 companies , showed Sales revenue $753.57 Billion and total employees (including supply chains) 2.4 Billion.	Deloitte, 2018
2019	Civil Aviation.	• Predicted demand between 2019 and 2038 estimated at 39,210 and 44,040 for new civil aircraft.	Airbus, 2019m; Boeing, 2019z.
2021	Aircraft and associated equipment.	• UN database of trade in goods, analysis of commodity code 792 Aircraft and associated equipment: (1) sales revenues of $7,046,761 Million; (2) destination of exports: (i) USA; (ii) France; (iii) Germany; (iv) UK; (v) Canada; (3) net exporting areas: (i) Europe; (ii) North America	UNComtrade, 2021.

2.2.6.8 AD sector during the Covid-19 pandemic

The Covid-19 pandemic has severely impacted the civil aviation sector, where the basic operating premise is to transport people and goods across national and international boundaries. The outbreak of the Covid-19 pandemic from the start of 2020, saw a sharp decline in passenger numbers within the Civil aviation sector due to travel restrictions estimated at resulting in declines in passenger footfall estimated to range from 60% to 90% of 2019 figures (Aislelabs.com, 2020; IATA, 2020). The civil aviation sector prior to the outbreak of Covid-19 had been transitioning from article sales only model towards a Servitisation model (Baines, et.al, 2009; Wallin, 2013; IFS, 2017; Tauqeer and Bang, 2018) which resulted in major civil aviation suppliers adopting servitisation in terms of: (1) article only sale with service offerings or (2) a complete service offering, where the approaches were widely adopted on the basis of civil aviation sector articles (aircraft, aero-engines, etc.) having long very useful working lifecycles, where enabling a Servitisation model was seen by many AD actors as maintaining a long-term strategic revenue stream. Servitisation works based on airlines flying aircraft, with a vastly reduced number of aircraft flights, has resulted

in a sharp decline in revenue, as a direct impact of Covid-19 pandemic leading to sharp reductions in aircraft being manufactured and delivered, with the resultant employee headcount and reduction in the amounts of articles being sourced from the supply chain, the impacts of the Covid-19 pandemic within the civil aviation sector are estimated to take at least 3-5 years to recover to 2019 levels (BBC, 2020b; BBC, 2020c; BBC, 2020d; Defense and Security Monitor, 2020; FT, 2020b; FT, 2020c). Net losses for 2020, across the sector have been estimated at $118.5 billion (IATA, 2020), the sharp decline within the sector has resulted in airline closures, deferment of orders from airlines and lessors. Projected losses for 2021 estimated at $38.7 billion, based on improvements expected to occur within the sector from the second half of 2021, (IATA, 2020).

2.2.6.9 UK AD sector following Brexit

The size of the UK AD sector has been identified in Table [2-12], the data shows increasing turnover and a reduction in employees for both Aerospace and Defence sectors, in the years prior to Brexit and Covid-19, the ADS data for 2020 is based on 2019 data.

Table 2-12: UK AD Sector Overview

Year	Sector	Turnover (Billion)	Exports (Billion)	Direct employees	Source(s)
2017	UK Aerospace	£32	£28	120,000	ADS, 2017; ADS, 2018; ADS, 2019; ADS, 2020.
2018		£35	£30	123,000	
2019		£36.9*	£34.2	111,000	
2020		£33.9	£31.8	114,000	
2017	UK Defence	£23	£8.7	142,000	
2018		£22.1	£7.3	140,000	
2019		£22.7	£6	135,000	
2020		£24.4	£10.9	132,000	

*2019 was the first time ADS split aerospace into 75% civil and 25% defence sectors.

Throughout the Brexit discussions some key concerns expressed by the UK AD sector included: (1) the need to prevent the free movement of articles being restricted between the UK and the EU; (2) loss of potential future competitiveness due to the UK AD sector no longer being able to access EU research funding; (3) EASA article type approvals, the authority to manufacture articles being revoked for the UK AD sector in the event of the UK withdrawing from EASA, resulting in UK AD sector organisations having to seek EASA type approvals, from registered offices in the EU in order to place articles from the UK into the EU; (4) EASA MRO type approvals being revoked, preventing UK AD sector organisations from being able to repair articles for EU-27 member state based organisations; (5) resultant loss of talent from the UK AD sector leading (Airbus, 2017; Boeing 2017). Civil aerospace articles remain free of tariff charges for the 32 signatories of the Agreement

on Trade in Civil Aircraft, 1980 (WTO, 2020). However, as a result of the requirements for the UK-EU Trade and Cooperation Agreement (Gov.uk, 2020), additional documentation is now required in order to maintain compliant to the process, to enable articles to be placed onto the EU / UK AD marketplaces, these additional tasks include: (1) ensuring the AD articles are certified by the applicable approval body allowing access to the marketplace, namely US FAA, EU EASA and the approval processes to be developed by the UK Civil Aviation Authority (CAA) during 2021 (CAA, 2020); (2) no reciprocal agreements on article type and MRO approval exist currently between EASA and CAA; (3) protection of data flowing between the UK and the EU; (4) identification of country of origin information in relation to AD articles to ensure local content provision requirements are met to ensure free trade in AD articles; (4) transfer of data submitted by UK located AD organisations, exported from the ECHA REACH-IT system into the UK REACH-IT system; (5) any authorisations and exemptions previously requested by UK AD organisations into EU systems becoming void, with the expectation that the approvals will need to be new requests within the UK REACH-IT system; (6) AD organisations in the UK and EU will have to maintain compliance to each regions applicable chemical regulations in order to maintain article compliance to being placed onto the marketplace. Beyond the impacts of the Covid-19, the new data collection and reporting requirements will present the AD sector in the UK and EU with significant additional challenges.

2.2.7 Current state issues with AD sector, supply chain data collection activities

2.2.7.1 Globalisation

Globalisation emerged as a by-product of technological innovations such as the internet, enhanced data communication networks, software applications like web browsers providing a visual interface, enabling the mass mobility of information, articles, and services. Consumer choices are no longer limited to the local / national supply chains, articles can now be purchased from anywhere in the world, 24 hours a day (Prahalad and Hamel, 1998; Min and Zhou, 2002; Woinaroschy, 2016; Dias and Ierapetritou, 2017; Hopper, Lassoud, Soobaroyen, 2017). The increased availability of articles has initiated a proliferation of alternative sources of articles disrupting the traditional supply and demand models. The internet has enabled increased outsourcing of article manufacture from local, high-cost manufacturing regions to lower cost regions. SCM strategies have had to evolve to incorporate the management of multi-vendor sourcing of raw materials, semi-components,

components and finished articles across a diverse and complex global supply chain (Freeman and Cavinato, 1990; Prahalad and Hamel, 1990; Barney, 2012; Úbeda, et al., 2015).

2.2.7.2 Article number serialisation issues

Where a finished article number is identified as a safety critical component, then it will contain a unique serial number that enables the traceability of the article to a specific revision and version number. This data must be provided in the aircraft logbook. The downstream users of the safety critical articles, the airline operators, have a duty to maintain the logbook information in relation to any updates undertaken, which includes modifications occurring during a repair cycle to bring an article to the latest revision standard, this activity occurs when safety critical articles enter a repair shop for maintenance activities. However, if a finished article is not a safety critical component, then the traceability of any modifications is much more a complex process, particularly when trying to identify the chemical substances used to maintain the article(s) in question.

2.2.7.3 Material specification issues

Additional complexity comes in the form of the specifications that identify the chemical substances, mixtures and materials which may be used to manufacture articles. Two distinct types of specification types exist: (1) material specifications that define the chemical substances, mixtures and materials which appear on the finished articles, and (2) process specifications that define the chemical substances, mixtures and materials used in the process of manufacture. Specifications are usually identified against the engineering geometry drawings, where there is a tendency to only update a geometry drawing in the event of a change in *'fit, form and functionality'* for a given article. Material functions (departments) within AD companies tend to update the material and process specifications with additional substances, mixtures, and materials data, marking any newly regulated chemical substances as either no longer used or as becoming optional. This puts a reliance on either internal processes or supply chain requirements to ensure suppliers manufacture articles to the latest information as stated in the material and process specifications, which is often not the case. Material functions work in this manner, primarily due to the costs of updating a drawing and performing the configuration management activities and costs for transmitting the updated geometry drawings across the supply chain. The cost of drawing change alteration and supply chain transmittal has been estimated at in excess of £10 Thousand per drawing sheet update (Takhar and Liyanage, 2017b; Takhar and Liyanage, 2018a). The author has identified the same consistent issue across several AD organisations, which has resulted in

a large volume of data ambiguity occurring internally and across a supply chain, especially when trying to identify the precise chemical substances used in the manufacture of articles, requiring the use of supply chain chemical substance reporting to collate the required information.

2.2.7.4 Multiple Article Numbering Systems

Figure [2-9] depicts the various internal article numbering sub-systems which may exist within an AD organisation, these sub-systems are often replicated across multiple supply chain actors within the AD sector. Company specific internal article numbers are often used to protect Confidential Business Information (CBI) data where different AD product manufacturers use internal article numbers to mask common article numbers purchased from the same article manufacturer.

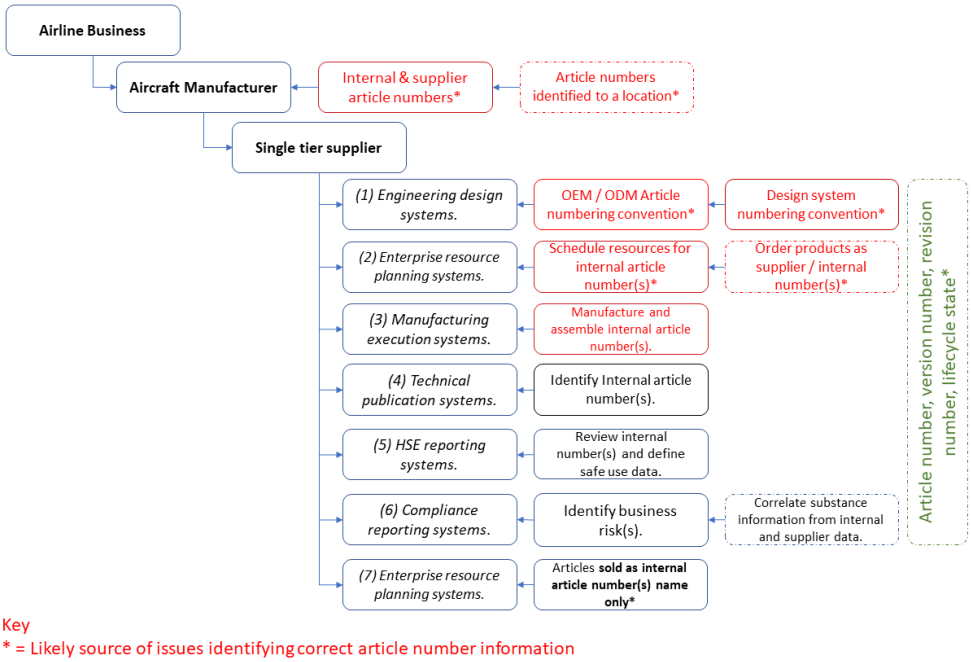


Figure 2-9: Examples of different article numbering systems used in AD organisations

In the context of this research study, the author has assumed the use of internal article and supplier article numbers to identify articles impacted by chemical regulations.

2.3 [RQ2] How should AD actors (internal and supply chain) and data elements be conceptualised in a framework?

In this section, the common AD internal actors are defined in section 2.3.1, followed by the identification of AD external actors in section 2.3.2. Data exchange standards are then examined in section 2.3.3, in terms of supporting the exchange of information in a consistent

manner between multiple actors in a supply chain. The data exchange standards have been examined within this research context to identify data elements which may be encompassed within the theoretical framework. Non-AD sector examples of supply chain data collection are examined in section 2.3.4.

2.3.1 Identification of AD organisation internal stakeholders

Initial state AD organisation internal actors / stakeholders, based on Authors previous AD experiences are identified in Table [2-13]. These stakeholders will be analysed further in the context of the development of the theoretical and conceptual frameworks.

Table 2-13: AD organisation internal actors / stakeholders

Name of business function	Expected role(s) within conceptual framework
Materials. *	• Generate the specifications (material / process based) with details of applicable chemical substance(s); mixture(s) or material(s).
Design. *	• Generate individual geometry drawings for article(s) referencing specifications.
Engineering.	• Responsible for article transformation cycle for internally produced articles.
Purchasing.	• Responsible for purchasing substances, mixtures, materials, and articles from the AD supply chain. • May elect to outsource manufacturing of internally defined articles to the AD supply chain.
Stores.	• Receipt, internally distribute / dispatch to customers chemical substances, mixtures, materials, and articles.
Health, Safety and Environment (HSE) / Environmental, Health and Safety (EHS).	• Ensure safety of employees, users of articles and the environment.
Sales.	• Communicate with the customer and provide any regulatory reporting as required.
Quality.	• Maintain consistent process and procedures across the AD organisation.
Compliance.	• Highlight potential business continuity risks of any articles that may contain regulated substances. • Perform obligatory notifications and reporting tasks as a supplier, as defined applicable within a chemical regulation.

*Where the AD organisation is responsible for the design of an AD article(s).

2.3.2 Typical AD sector supply chain actors

Figure [2-10] presents a holistic view of typical AD supply chain actor types.

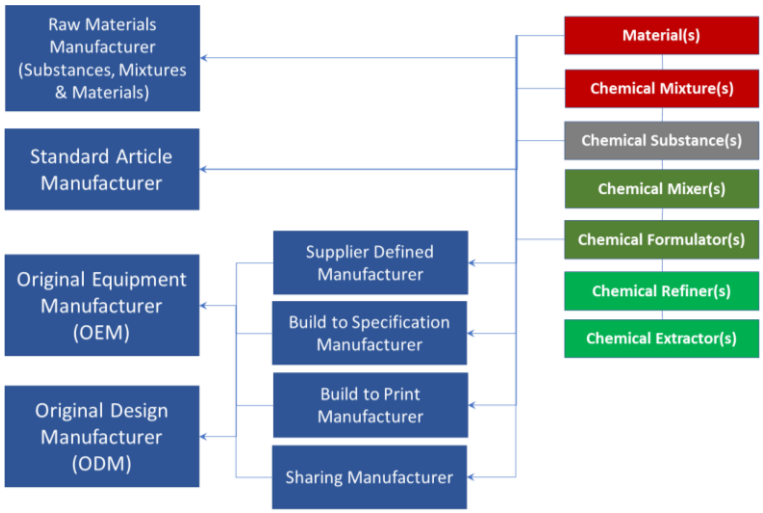


Figure 2-10: Typical AD supply chain actor types

AD supply chain actor types can be described as: (1) chemical substances, mixtures, and materials suppliers – providing essentially the raw materials; (2) standard article suppliers providing industry standard articles manufactured against industry standard specifications; (3) supplier defined articles; (4) ODMs providing article designs, where article manufacturing may be licensed to external parties; (5) OEMs design and manufacture articles internally or using other supply chain actors; (6) build to print suppliers produce articles to precise OEM design and material specifications; (7) build to specification suppliers where suppliers are allowed flexibility in the selection of materials which can be used; (8) sharing suppliers, a buyer-supplier relationship extended to include joint ventures / risk and revenue relationships where the costs of article design are shared between a buying organisation and its supplier are shared as are future potential sales revenue for a given article. The identification of AD supply chain actor types and the use of chemical substances, mixtures, and materials across the article transformation cycle aids organisations to understand and assess potential environmental and business continuity risks as well as enhancing product design and development.

2.3.3 Complex AD Buyer Supplier Relationships

Complex buyer supplier relationships exist, within the AD sector supply chain which can augment the assumed traditional supply chain management model, for example: (1) parent AD buyer organisation owning a supplier organisation which is a subsidiary of the parent organisation, which makes the process of stakeholder and data identification complex, this situation typically results from a process of mergers and acquisitions; (2) risk and revenue sharing partnerships, where a supplier financially participates in a new article development process with a customer, in return for a share of the long term profits generated from the sale

of the new article; (3) joint ventures, where a buyer and supplier organisations both invest jointly in a new organisation to develop new technologies and articles, sharing profits; (4) buyer loans supplier low interest funds, this scenario occurs for example where a new chemical regulation requires high capital investment to replace existing manufacturing systems which may need to be updated following the introduction of a chemical being restricted such as trichloroethylene being restricted across the EU, resulted in requiring large scale investment in existing manufacturing systems (Aerospace Manufacturing, 2017), this was experienced by the author first-hand, where suppliers needed to request investment funds from their respective customer in order to support the replacement of trichloroethylene which became a restricted substance following it's EU REACH Authorisation sunset date (ECHA, 2021c) in 2016, whereby it's usage within the EU is now banned unless, an authorisation approval was granted, the AD sector did not actively pursue an EU REACH Authorisation for continued usage and hence it was banned within manufacturing processes across the AD sector, which entailed the need for suppliers needed to invest in replacement machinery, in order to continue to support the production of AD customer articles.

2.3.4 Data Exchange Standards

2.3.4.1 Most Widely Adopted Data Exchange Standards

Data exchange standards are maintained via Standards Body Organisations (SBO). Data exchange standards are created by industry, software solution providers and consultants voluntarily participating in applicable SBO committee meetings. Figure [2-11] depicts the most adopted global data exchange standards.

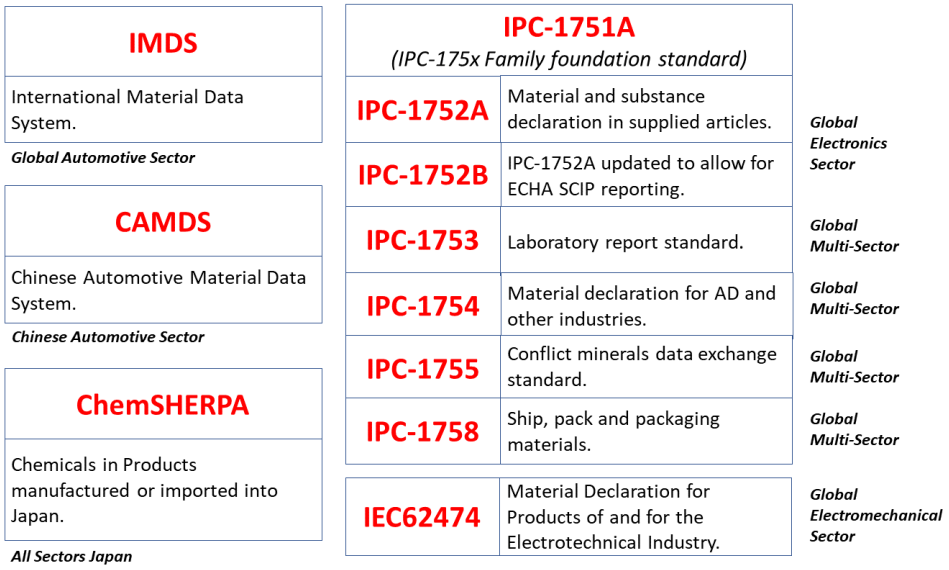


Figure 2-11: The most widely adopted supply chain data exchange standards
Source: CAMDS, 2020; ChemSherpa, 2020; IEC, 2019; IMDS, 2019; IPC-1751A, 2020.; IPC-1752A, 2019.; IPC-1753, 2020; IPC-1754, 2019; IAEG AD-DSL, 2019; IPC-1755, 2020; IPC-1758, 2020; SAE, 2008.

The main aims of data exchange standards are: (1) to enable data to be exchanged in an electronic manner, similar in context to industry common reporting templates, with a declarable substance list; (2) define an agreed set of data fields which can be used by solution providers and industry using XML forms and templates; (3) development of an XML schema allow the agreed data fields to be transmitted in an electronic manner between a data requesting organisation and a responding organisation.

2.3.4.2 Data Exchange Standards: Article Statements and Declaration Types

A common feature of data exchange standards are their abilities to handle Article statements, partial material declarations and FMDs as shown in Table [2-14].

Table 2-14: Article declaration statements

Use Case	How they are typically handled in a data exchange standard
Product statement.	Query lists: propose a question such as *Does your article contain any substances regulated under [regulation name]?* – Supplier responds with a yes / no response. Where a Yes response requires population of at least the partial material declaration, whilst a No means that the article the declaration pertains does not contain any regulated chemical substances.
Partial material declaration.	Supplier provides chemical substance information in relation to the regulatory context, for example, providing data on chemical substances regulated under EU REACH, EU RoHS, or an industry specific DSL such as IAEG AD-DSL (AD).
Full material declaration (FMD).	The supplier provides in addition to a partial material declaration all other chemical substances found in articles.

2.3.4.3 Data Exchange Standards: Main Article Level Data Elements

Main article level data elements used within data exchange standards are shown in Table [2-15].

Table 2-15: Main article level data elements used data exchange standards

Area	Sub-Area	Meaning
Version.	Data exchange standard XML schema.	Name, publication date, version number, baseline XML schema for the data exchange standard.
Requestor information.	Contact details, location, date of request.	Identify who is requesting supply chain data.
	Identify internal part numbers.	Requestor needs to highlight any internal article numbers which pertain to supplier part numbers, useful for cross-referencing data.
	Identify article numbers.	Identify article numbers as provided by a supplier.
Compliance statement (Requestor).	Identify regulatory context.	Identify applicable regulation(s) and dates of publication.
	Declarable / Reportable Substance List.	The chemicals of concern to be reported with applicable version / publication date.
		Unique list specific identifiers, ideally a CAS / EC number per chemical substance with the name of the chemical substance itself. In the event of missing CAS / EC number a unique identifier may need to be assigned.
Supplier details.	Contact details, location, date of request.	Identify supplier details.
	Identify article numbers.	Supplier identifies article numbers as sold.
Compliance statement (Supplier).	Identify regulatory context.	Identify applicable regulation(s) and dates of publication.
	DSL.	The chemicals of concern to be reported with applicable version / publication date.
		Supplier to report using CAS / EC and substance name and/or with unique identifier provided by the requestor.
	Reportable information.	Pertain to the type of information reported by a supplier usually at: (1) simple Yes / No statements; (2) reporting against specific material group level; (3) substance information as per a regulation or; (4) Full Material Declaration (FMD) level.
	Supplier article number compliance information.	Supplier to follow 'Once an Article Always an Article' principle in reporting any chemicals of concern information from the lowest level article within the supplier article.
Supplier sign-off.	Supplier statement.	Supplier attests to the completeness of the information provided, with any caveats covering incomplete / missing information.
	Supplier signature.	Supplier authorized person confirming data provided is complete.
Attachments.	Attachments.	Enables Requestor / Supplier to attach additional documentation to the material declaration request.

2.3.4.4 Data Exchange Standards: Full Material Declarations (FMD)

FMD is an approach based on collecting all the chemical substance related information from a supplier in a single declaration request, to enables the requestor to obtain a full substance list of chemicals used to produce the finished article supplied to the requestor. The

advantages of using FMDs include: (1) future proofing supply chain chemical substance reporting requirements by having clear visibility of all chemicals substances within a given procured article that a supplier has provided an FMD against; (2) enables collection of all the required information from an article supplier in a single reporting cycle, without having to go back to a supplier at every update of a given regulatory substance list; (3) in requesting and collating information once, costs are assumed to be less than frequent requests for information from suppliers. The disadvantages of FMDs include: (1) suppliers will still need to inform requesting companies in the event of different chemical substances ad mixtures used to manufacture article, this process needs to be agreed as part of any FMD data acceptance criteria; (2) response rates from suppliers to FMD requests are often much lower than requesting compliance statements for regulations where suppliers report on chemical substances they are legally obliged to report against; (3) supplier reluctance to providing FMD information which is often seen as providing too much Confidential Business Information (CBI); (4) the source of the information needs to be verified from a supplier, in the event that they have used a third party data source (databases) to provide data which could potentially provide inaccurate data: (5) FMD declaration by themselves are statement of all the chemicals contained within a article which may result in requiring additional data elements needed for a specific regulation for example a chemical of concern may appear on the EU REACH regulation with just the name of the chemical substance and appropriate safe use guidance, whilst the same chemical substance under EU RoHS will require additional data on the amount of the chemical found in a product and additional information on any exemptions obtained in order to use the same chemical on an electronic article. FMD data collection is often seen as the utopia for supply chain chemical substance reporting, it often takes several rounds of EU REACH and EU RoHS reporting to be requested from the supply chain first, followed by clear contractual requirements to ensure article suppliers understand their reporting obligations. The conceptual framework to be developed within this research study needs to ingest data created via a data exchange standard as it will form a consistent set of data elements that are exchanged between different actors in the AD supply chain. Within this context, the author helped develop the IPC-1754 data exchange standard for the AD sector and will utilise the main data elements from IPC-1754 within the conceptual framework.

2.3.5 Review of supply chain data collection review in non-AD sectors

This section presents a review of current state approaches to supply chain data collection processes in non-AD sectors in relation to reporting against chemical regulations.

2.3.5.1 Automotive sector

The Automotive sector is very similar to the AD sector in terms of the amounts of electronic and mechanical components contained within a typical article(s). The International Material Data System (IMDS) is the Automotive sectors centrally hosted solution for supply chain chemical substance reporting, IMDS was first implemented in June 2000 (IMDS, 2019). IMDS was updated in 2005 with the Global Automotive Declarable Substance List (GADSL), which is the single declarable substance list for the Automotive sector, based on assumed regulations impacting the Automotive sector (GADSL, 2019). IMDS is financially supported by the top OEM automotive vehicle manufacturers who fund the system development and management by a third-party solution provider. Reporting into IMDS assumes all the supply chain actors feed data into the central system, which in turn flows data upwards to the required OEM requesting information. To transact with other actors within the automotive supply chain, suppliers must comply with the Product Pre-Approval Process (PPAP), which requires suppliers of articles to provision data on chemical substances within articles to the IMDS system. The basic logic of requestor and responder data requests is shown in Figure [2-12].

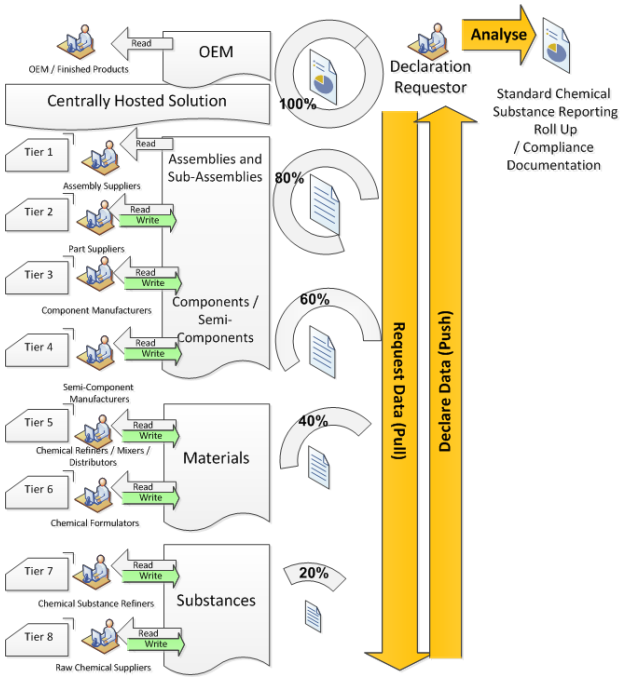


Figure 2-12: IMDS Automotive sector centrally hosted chemical reporting system

Despite using standardised reporting formats, issues with IMDS have arisen where different OEMs interpret the IMDS reporting requirements are subtly different from one OEM to another, there are over 25 separate OEM reporting requirements (IMDS, 2020). IMDS has had issues where despite reporting data to get product approvals issues have led to recalls:

(1) Continental and Bosch admitted in 2019 that despite capacitor-outfitted circuit boards marketed as "lead-free" actually contained reportable lead at .0003 grams present per article (Assent Compliance, 2019a), this was later identified as being an issue related the manner in which IMDS data was collected under IMDS REC019, which enabled chemical substances in electronic articles supplied to the Automotive sector in an aggregated manner, not at an individual article level as required by regulations such as EU REACH (EC, 2006a). This has led to IMDS adoption of IPC-175x and IEC 62474 data exchange standards; (2) Volkswagen motors had to perform a major recall in 2019, when a supplier declared data to the IMDS system, then then manufactured articles containing banned substances (Assent Compliance, 2019b). IMDS reporting system was intended to become the single global reporting system, since its inception additional reporting requirements for the Automotive sector have arisen from: (1) China implementing its variant of IMDS named China (2) Japan via the JAMA/JAPIA standard material data sheet standard requires automobile manufacturers to collate information on chemical substances to meeting both Japanese and international regulations; (3) new reporting requirements being developed under USMCA to report hazardous chemicals and labour cost rates.

2.3.5.2 Electronics sector

The electronics sector faces a similar set of regulations to the Automotive and AD sectors. The electronics sector has developed supply chain data collection systems using data exchange standards with reporting templates and utilisation of non-centrally hosted reporting solutions. Non-centrally hosted solution would entail either: (1) 'top down' data requests from an OEM / third-party solution provider, or; (2) 'bottom up' data requests being transmitted from the lowest supply chain tier upwards. In a non-centrally hosted solution data flows across a supply chain, without a single industry central repository storing the collated data, as shown in Figure [2-13].

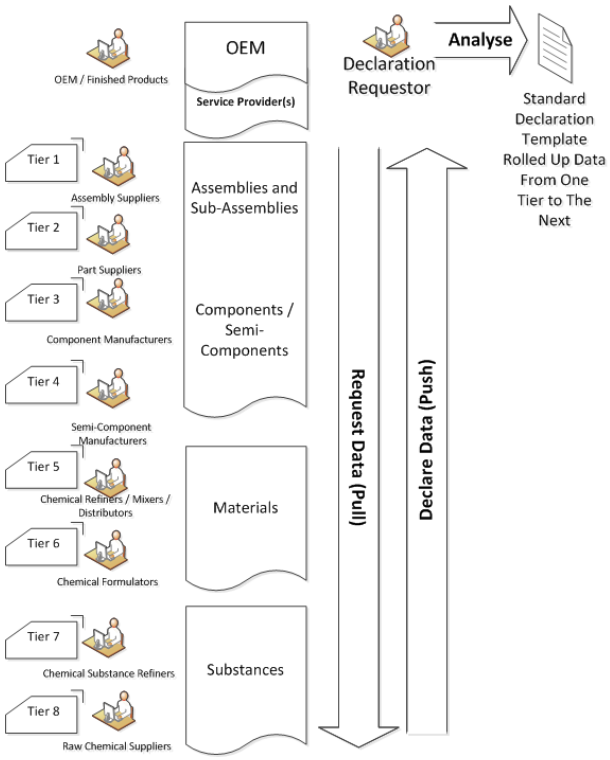


Figure 2-13: Non-Centrally hosted supply chain chemical substance reporting system

The Electronics sector was able to adopt a 'Bottom Up' approach towards chemical substance reporting, due to the lowest level articles (capacitors; resistors; IC's; LED's; Diodes) being defined against very rigid specifications, which detail both functional and material requirements. Unlike the Automotive IMDS system, the electronics sector adopted the approach of creating open data exchange formats with XML schema to enable data to be parsed across the supply chain. The main data exchange standards in use within the electronics sector are IPC-1752A/B (IPC-1752A, 2019) and IEC62474 (IEC, 2019). IPC-1752A/B allows for multiple substance lists to be reported against, IEC62484 defined its own specific substance list based on EU REACH SVHCs and EU RoHS substances found within the electronics sector. IPC-1752A/B is widely used in North America and Europe, whereas as IEC62474 is more widely used in Asia and Europe. There are still a few differences between the two standards which need to be resolved to allow data from one standard to be 100% parsed against another. There is no single provider of a service to both standards like Automotive sector. The Electronics sector has assumed that all IT solution providers will compete not just on the basic supply chain data transmission, storage and retrieval process and related pricing along rather that they will compete against each other with additional and value-added services related to deeper supply chain reporting, deeper value-added analytics, etc.

2.3.5.3 Other sectors

Approaches utilised in other sectors are shown in Table [2-16].

Table 2-16: Summary of data collection standards used in other industry sectors

Sector	Description	Standards	Regulation	Comments	Source(s)
Medical Devices (MD).	Regulatory substance list references chemicals on EU CLP, EU REACH, EU BPR. Device manufacturers must collect data on substances justifying where present in any article as part of the device approval process.	IPC-1752A/B IEC62474.	EU Medical Device Regulation.	Data reporting formats are not fully established. Regulations implemented to ensure device manufacturers implemented QMS and configuration management systems to report and justify substances used in articles.	EU, 2017b.
Pharmaceuticals.	FMD reporting is a key feature of the pharmaceutical sector reporting data at each manufacturing batch level.	Custom organisation specific FMD reporting formats.	Good Manufacturing Practice.	Increasing counterfeiting issues with manual paper-based records has resulted in the increased use of data being securely encrypted in electronic formats, the sector has seen the adoption the use of blockchain technologies to ensure transactional information can be audited.	EMA, 2020; Mackey and Nayyar, 2017.
Shipping.	Identification of hazardous materials which is created by the original ship builder and then maintained by the ship owner(s) until such time that the shipping vessel is recycled.	IMO IHM: (non-EU); EU Ship Recycling Regulation (EU SRR) (EU).	IMO IHM, EU SRR.	IMO IHM: substance list and template (non-EU) EU Ship Recycling Regulation (EU SRR): substances list (EU). Global maritime authorities may onboard a ship at a given time to inspect the IHM, failing to provide this data can result in a ship being refused entry at a port of call.	IMO, 2009; EC, 2013.
Railway.	Industry DSL known as UNIFE Railway Industries Substance List known as the RISL.	Industry DSL and custom reporting template.	EU REACH, EU CLP, EU RoHS, EU BPR.	Limited adoption of the custom reporting template. Standard practice is to use the RISL, with IPC-1752A/B reporting format.	UNIFE, 2016.
Textiles.	Two industry DSLs to report the use of restricted hazardous substances.	AFIRM list, ZDHC list.	All global regulations impacting textiles sector.	There are no defined reporting formats for the textiles sector.	AFIRM, 2021; ZDHC, 2021.
Japan (all) ChemSHERPA Tool.	Cross-sector tool for industry to report chemical substances in articles manufactured within and imported into Japan.	Bespoke adaption of IEC62474.		Widely adopted reporting format for article manufacturers and importers.	ChemSHERPA, 2020.

2.4 [RQ3] How can data be ingested from multiple sub-systems, correlated, reviewed, and assessed in a framework?

This section explores how data from multiple sub-systems could potentially be collated and assessed to identify the potential impacts posed to the AD sector from chemical regulations. The research context is presented in section 2.4.1 presents the research context. Section 2.4.2 examines how are data may be identified in terms of existing frameworks and standards. Section 2.4.3 identifies the use of chemical regulation substance lists as cross reference points.

2.4.1 The Research Context

As this research study intends to develop a framework to evaluate the effects of chemical regulations on the AD sector, it is necessary to clarify the term "effects of chemical regulations" as shown in Figure [2-14] which is used to describe: (1) the identification of articles supplied by a given AD organisation, leading to; (2) the identification of article source of supply, and; (3) identification of the technical design authority responsible for article design, leading to; (4) collation of data from internal and external supply chain actors in a harmonized format, and then; (5) examine the impact of using a given chemical substance against different chemical regulation substance lists, to finally; (6) determine and manage applicable risks such as reporting and notification obligations, which could potentially then result in business continuity risk(s).

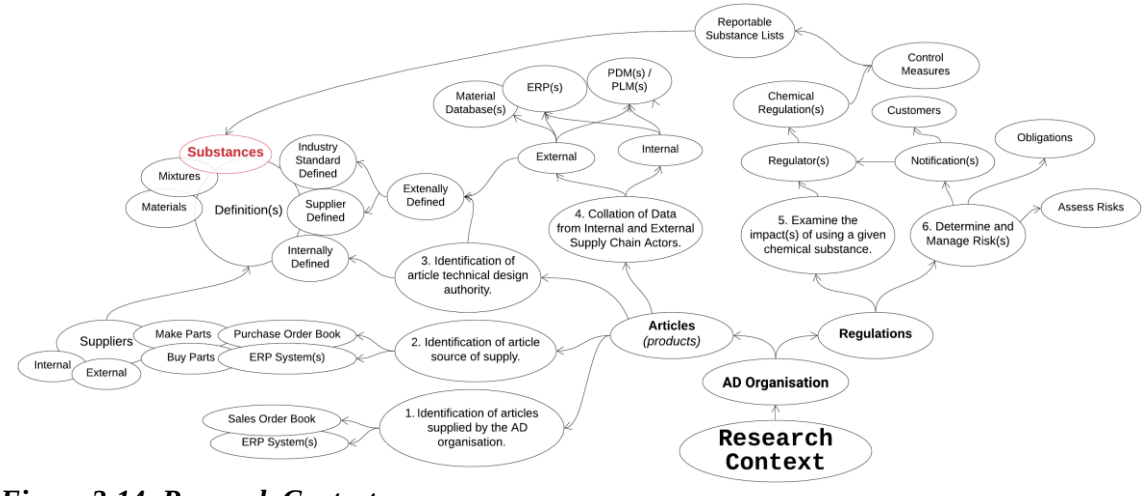


Figure 2-14: Research Context

2.4.2 Towards Effective Identification of Articles and Chemical Substances

Existing frameworks and standards provide a view on how current state data collection and reporting is being undertaken. Figure [2-15] depicts a review of existing frameworks and standards which highlighted existing research gaps in terms of: (1) frameworks and standards that focus less on the identification and control of hazardous substances but more on the use of sustainable chemicals, reduced energy consumption, increased recycled materials usage (ISO 14040:2006; ISO 2600:2010; ISO 15686-5:2017; GRI, 2020; UN, 2020); (2) frameworks and standards that examine hazardous chemicals management, fall into the HSE / EHS arena where identification of harmful chemicals and potential employee and product safety concerns take precedence over observation of chemicals to reportable chemical regulations, and; (3) frameworks and standards that generate eSDS/ SDS / MSDS data for downstream users where the focus is on identification of chemical substances supplied on their own, within mixtures or materials only with referencing to chemical regulations, however these commercial systems do not focus on the rest of the article transformation cycle, in terms of being generated for articles produced from chemical substances, mixtures and materials; (4) existing data exchange standards (IPC, 2021; IMDS, 2019; IEC 62474, 2019) focus on harmonised data elements allowing for the data collection of new purchased article data rather than provisioning a view of externally source and internally manufactured articles; (5) multiple material data systems storing substances, mixture and material data against specifications, which are then; (6) referenced within PDM / PLM systems storing the engineering design data, utilised within; (7) internal manufacturing cells or outsourced from a supply chain; (8) standards body organisations that define industry standard parts for use in AD sector; (9) against which applicable chemical substance data needs to be collated and analysed against (10) multiple chemical regulations.

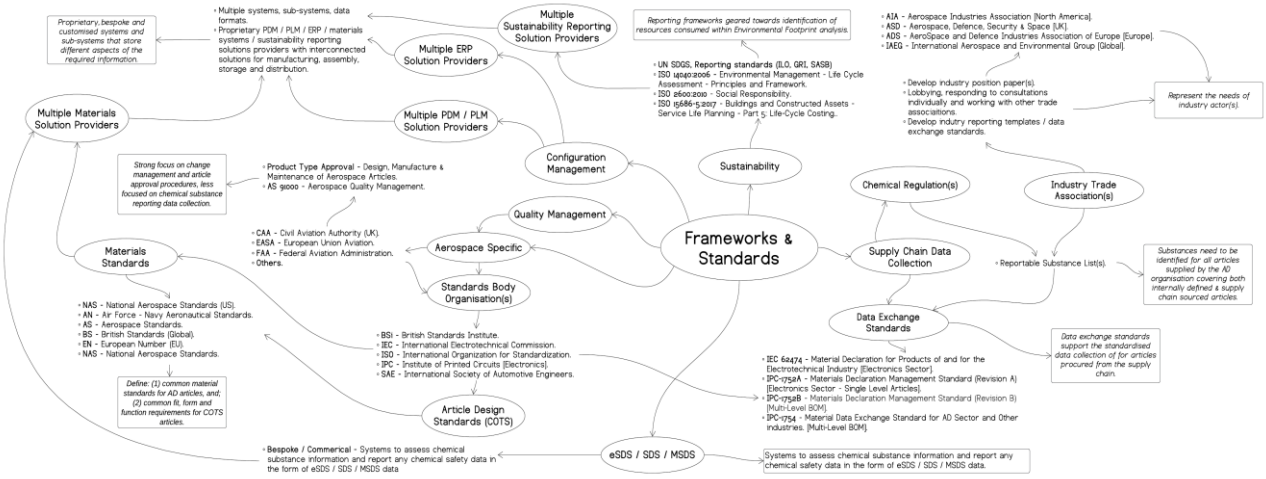


Figure 2-15: Frameworks and Standards
Adapted from: ISO, (2006); ISO, (2010); ISO, (2017); IMDS, (2019); IEC 62474, (2019); GRI, (2020); UN, 2020; IPC, (2021).

2.4.3 Identification of impacts posed by chemical regulations

The impacts posed by chemical regulations can be defined in terms of a given Declarable Substance List (DSL) as defined within a chemical regulation(s), are shown in Table [2-17].

Table 2-17: Chemical regulation DSL types

DSL type	Meaning	Expected triggers to be developed within framework

Initial watch list.	• Initial list of substances that require action(s).	• Identify use of the substance(s) within internal definitions:
		  ○ Article names and numbers from applicable BOMs.
		  ○ Geometry drawing data (if applicable).
		  ○ Material / process specifications, usually from geometry drawing data (if applicable).
		  ▪ Extract substances, mixtures, and materials data.
		• Identify use of the substance(s) within externally procured articles:
		  ○ Supplier defined Article names and numbers from applicable BOMs.
		  ○ Supplier identification of chemical substances within provisioned articles.
		• Roll up internal definitions that identify chemical substances and supply chain collected data.
		• Cross reference applicable DSL to identify potential risks posed by a given chemical regulation – based on the identified DSL name.
		• Review downstream user documentation, perform safe use assessment, provision safe use guide,
		• Review downstream user impacts:
		  ○ Review existing documentation.
		  ○ Identify if the chemical substance is present on the finished article and exceeds the nominal 0.1% w/w threshold level on a finished article (the common threshold level in most chemical regulations.
		  ○ Perform safe use risk assessments.
		  ○ Generate safe use guidance.

DSL type	Meaning	Expected triggers to be developed within framework
		○ Generate applicable chemical regulation, downstream user notifications. ○ Perform any additional reporting as defined within a chemical regulation. • Perform obligatory reporting tasks and undertake any risk mitigation activities.
Authorised usage list.	• List of controlled substance(s) that require an approval to be used within a specific region. • Permitted use authorisation is allowed where the substance is identified as being essential for an article to function safely.	• All the above (initial watch list). • Identify locations where used (internally and across the AD supply chain. • For internally defined articles, where a substance requires a permitted use authorisation, compile relevant documentation, and submit for approval. • For externally procured articles, ensure the supplier is aware of the need for a permitted use authorisation and has undertaken steps to request an authorisation. • Having no approved authorisation(s) in place, may result in an article not being allowed to be manufactured within a given region.
Restricted usage list.	• The most controlled DSL where a substance may be banned from a specific or in its entirety within a specific region.	• All the above (initial watch list). • Identify locations where used (internally and across the AD supply chain. • For all articles identify the actual context of the restriction as defined in the applicable chemical regulation, assess impact on the AD organisation.

2.5 [RQ4] How should the framework be implemented within a typical AD organisation to identify any potential impacts posed by chemical regulations?

This section outlines the conceptual framework to be developed as part of this research study. Section 2.5.1 presents the outcomes of an initial multi-industry consultation on supply chain data collection, conducted prior to the commencement of this research study. Section 2.5.2 reviews the use of readiness levels as a means of assessing supplier capability to provision data as well as feeding information into applicable gated reviews.

2.5.1 Outcomes from initial industry consultation on supply chain data collection

The author conducted an initial industry consultation during 2016, with 23 organisations from AD, Automotive, Heavy Machinery, distributors and consultants participated in a series of expert interviews (Takhar and Liyanage, 2017b). The main findings are presented in Table [2-18]:

Table 2-18: Findings from initial industry consultation

Topic	Respondent comments
Issues observed due to chemical regulations.	• Articles being withdrawn (as they contain restricted substances), the end user may become aware of reduced supply, only when it is too late.
Needs of a chemical reporting system.	• Identify chemicals used internally and externally across the supply chain. • Where substance usage exceeds a threshold, level ensures applicable declarations / authorizations are made. • Analyse potential supply chain disruption (as formulators / chemical refiners become deterred from supplying restricted regions).
Regulatory awareness.	• Any chemical substance reporting system requires an awareness of how chemical regulations arise / change over time.
Map data needs.	• Identify competent users - Core users within a business who will handle the chemical substance reporting information. Identify who these people are, how the handle and process data.
Stakeholder engagement.	• Executive buy-in - Develop executive leadership buy-in early in the implementation process. Executives should be engaged to understand the impacts of non-compliance to chemical regulations (fines, business continuity risk, etc.)
Develop commonality.	• Mandatory / optional - Define which data elements are absolute and which are optional. • Full / partial / general disclosure - Define the way suppliers can respond. • Standards - There may be a need for creation of a specific data exchange standard such as IPC-175x to enhance the common data exchange format / template.
Legality.	• Terms and conditions - Optional specific common terms within contracts to ensure article suppliers provide generic or specific chemical substance data. • Supplier signature - Supplier sign-off as part of the audit trail.
Training.	• Need for training - Accurate and complete data from suppliers requires consistent supplier training across a supply chain. • Language - Training material should not be limited to one language, consider the end users of the data.
Communication.	• Clear lines - Clear lines of communication from the highest tier (top-level requestor / service provider) through a supply chain.
Supplier engagement.	• Avoid ambiguity - Communicate with the supply chain in a clear and consistent manner.
Recommendations.	• Analyse and keep reviewing the chemical regulations which are likely to have an impact on your organisation, create a declarable substance list. • Ensure early engagement with all relevant internal and external stakeholders. • Develop an agreed set of data elements which are understood by all. • Develop a template form which captures data against the data elements. This template may be in MS Excel or XML format. • The template form should be simple to understand and complete, the more ambiguous the structure, the lower the likelihood of completion. • Develop a detailed training plan. • Prior to full implementation, perform a detailed pilot and don't be afraid to pause, modify and then proceed with modifications to the existing standard.

The purpose of conducting the initial industry consultation during the literature review stage of this research study was to define an initial state baseline of activities, based on feedback from multiple sectors that need to be undertaken to support the implementation of supply chain data collection activities, which could be applied to the conceptual framework implementation.

2.5.2 Industry Readiness Levels Assessment

Readiness levels are a measure of maturity for a given article, process, software, which enable decision makers to make evaluations of internal / external activities. Readiness levels were first devised by NASA in 1974, and then formally published in 1989, as the Manufacturing Readiness Levels (MRL) (MRL Wikipedia, 2020), several additional readiness levels have evolved, and have been assessed in the context of this research study as shown in Table [2-19].

Table 2-19: Assessment of Industry Readiness Levels

Readiness	Suggested levels for regulatory compliance checks	Application in research	Source(s)
Manufacturing Readiness Level (MRL): 10 levels covering the manufacturing-based requirements.	MRL3: experimental proof of concept. MRL4: article validated in lab environment. MRL5: basic capability demonstrated. MRL6: process optimised for production rate. MRL8: full production process qualified. MRL9: full production. MRL10: continuous improvements.	**YES** MRL levels help define generic product lifecycle stages. Regulatory compliance checks need to be defined as part of standard gated review process.	DoD, 2008; Harris, et al., 2019; MRL Wikipedia, 2020.
Technology Readiness Level (TRL): 9 levels covering the technology (software / systems) based requirements.	TRL4: proof of concept. TRL5: rough working prototype. TRL6: prototype field trials. TRL7: pre-production prototype. TRL8: first production run. TRL9: full commercial production.	**YES** TRL levels help define generic software / system lifecycle stages.	Mankins, 1995.
Market Readiness Level: 10 levels covering the market readiness-based requirements.	Level1: basic research. Level2: needs formulation. Level3: needs validation. Level8: scalability.	**YES** Market readiness levels validate that a produced article meets market expectations.	Kobos, et al., 2018.
Supply Chain Readiness Level (SCRL): Conceptual 10 levels covering conceptual supply chain-based requirements, still in development, notional 3 levels were originally defined.	SCRL1: immature high risk / high cost. SCRL5: developing moderate risk / lower cost. SCRL10: mature risk mitigated / lowest costs.	**YES / NO** This framework contains several SCM aspects including setting standard evaluation criteria, framework contract with suppliers and methods to continuously monitor suppliers. However clear compliance requirements for regulatory reporting is not clearly visible in SCRL.	Tucker and Paxton, 2010.

Readiness	Suggested levels for regulatory compliance checks	Application in research	Source(s)
Integration Readiness Levels (IRL): 9 levels covering the integration between different systems and process-based requirements.	IRL1 - An Interface between technologies has been identified. IRL4 - There is sufficient detail in the quality and assurance of the integration between technologies. IRL5 - There is sufficient control between technologies necessary to establish, manage, and terminate the integration	**YES / NO** Identification of steps where conceptual framework requires integrations between sub-systems. The intended application of the conceptual framework is to enable data to be extracted from sub-systems and ingested via harmonised data load templates.	Hasenauer et al., 2016.
Regulatory Readiness Level: 5 level regulatory requirement levels.	RRL1: access to regulatory process. RRL2: security of political capital. RRL3: policy effectiveness.	**YES / NO** This readiness level sets high-level sustainability requirement goal setting for an organisation as opposed to a barometer to assess internal / external organisations.	Kobos, et al., 2018.

2.6 Chapter Summary

Companies who produce, distribute or market any kind of physical article onto a given marketplace are likely to impacted by several chemical regulation(s), which require reporting of chemicals of concern contained within finished articles. As chemical substances transform into mixtures, materials and articles, vast volumes of data need to be collated and analysed, observing identified chemicals of concern against specific chemical regulations to determine potential business continuity risks and reporting obligations. EU regulations such as EU REACH, EU CLP and EU RoHS are seen as the gold standard regulations, influencing the design of chemical regulations globally. The key principle behind all chemical regulations is that manufactures have some form of system to identify the required use of chemical substance information on their own, within mixtures and materials in a consistent manner. As chemical regulations expand the list of chemical substances to be reported, industry needs to maintain a consistent approach to requesting, collating and analysing internal product definitions data, and data from suppliers for externally defined articles. AD articles are defined via geometry drawings detailing the fit, form and function of the article which are then referenced by material / process specifications, which in themselves may call out several mandatory and optional substances, this requires the need to request substance information from suppliers as to the exact substances used to produce a given AD article. Substance information needs to be collated at the lowest article within a physical finished

article for example a jet engine may contain 12-15,000 finished lower-level articles, which in themselves may be formed from additional lower articles. This adds to the complexity of managing the data in a consistent norm. Existing practices of collating internal product definitions differ between every AD organisation, as the underlying sub-systems record data in numerous different formats and methodologies. Often suppliers provision data based on extracting substance information based on the mixture or material formulation data, straight from an SDS or MSDS which needs to be scrutinised in a consistent manner and not blindly ingested and reported by AD organisations. The key aim of this research study is to present a whole system view, where the theoretical framework defines the initial state actors, data elements and data model, underpinning the conceptual framework which via expert feedback on data model and reporting, outlines a harmonised approach to the process of identifying the risks posed by using a given chemical substance against a given chemical regulation to identify risks and then perform the associated risk mitigation actions.

Chapter 3: Research Programme Development

3.1 Introduction

The systematic literature review undertaken in Chapter 2 outlined the theoretical context based on the identification of multiple upon multiples of articles, supply chain actors, supply chains (civil, defence), chemical regulations, reporting requirements, reporting formats, data exchange formats, assumed data reporting levels, sub-systems where applicable source data is stored and maintained, all of which make the process of accurately and consistently identify any potential impact(s) of chemical regulations against typical AD organisations challenging. Research can be described as a systematic process aimed at discovering new understandings (Creswell, 2013b; Saunders et al 2015), therefore this chapter presents the justification of the research methodology used within this research study to meet the research aim, objectives, and research questions. Following a review of different research approaches, the adopted worldview is presented for the research, followed by the research strategy outlining the theoretical, conceptual, and empirical stages of the research study. The structure of this chapter is shown in Figure [3-1].

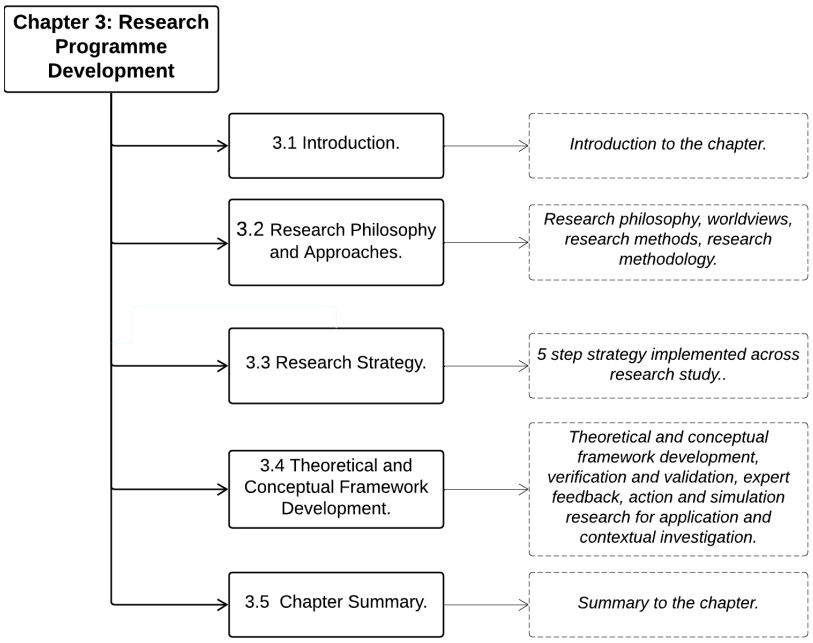


Figure 3-1: Chapter 3 Stracture

3.2 The Development of Research Aim and Objectives

3.2.1 Research Aim

The aim of this research is outlined as following:

To develop a conceptual framework enabling identification of articles (products) potentially at risk from chemical regulations supporting decision making processes for AD organisations.

3.2.2 Research Objectives

This following research objectives are identified to achieve the research aim:

- [RO1] To investigate existing methodologies used to identify chemical substances within AD articles.
- [RO2] To investigate chemical regulations that may impact the manufacture of AD articles.
- [RO3] To develop a framework to analyse the impact of chemical regulations on AD articles.
- [RO4] To evaluate the performance of the proposed framework using simulation.

3.3 Research Philosophy and Approaches

3.3.1 Research Philosophy

Figure [3-2] shows research broken down as: (1) a research problem identifying an issue / gap in knowledge, from which; (2) the research aim defines the scope of the research study; (3) research objectives describe the expected outcomes / achievements of the research project, and; (4) the research questions to be addressed which in turn, influences the research design.

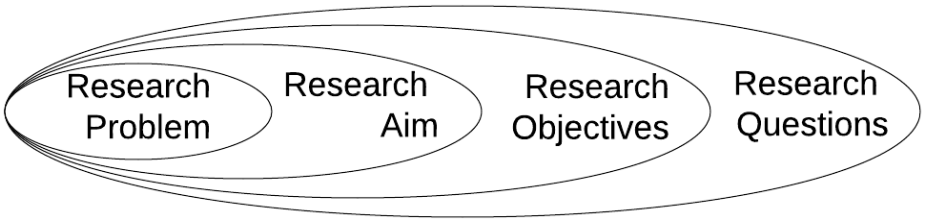


Figure 3-2: High-Level Anticipated Research Philosophy

Figure [3-3] shows the basic research philosophy being extended by actual truths and actual knowledge enabling the generation of the anticipated outcomes of the research study.

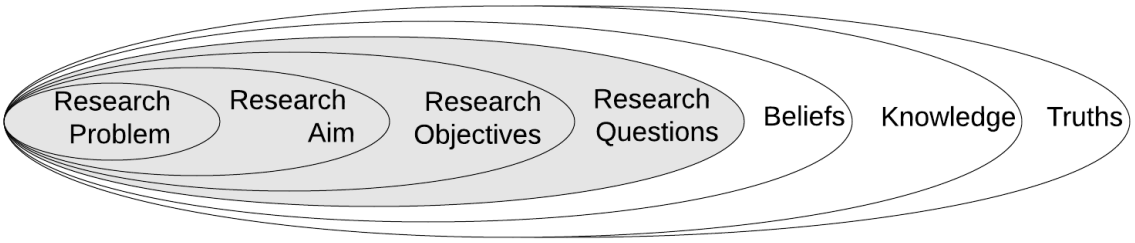


Figure 3-3: High-Level Anticipated Research Philosophy & Outcomes

3.3.2 Worldviews

Paradigms were originally defined as "an integrated cluster of substantive concepts, variables and problems attached with corresponding methodological approaches and tools" (Kuhn, 1962). The research paradigm is generated from the assumptions made by researchers, utilising ontology, epistemology, and axiology to derive a worldview that identifies "the individuals place in it and the range of possible relationships to that world and its parts" (Guba and Lincoln, 1994). A worldview may be considered as a societal or individual conception of the world based on the applicable knowledge, beliefs and assumptions of society or individual, which can guide the direction of further data collection, analysis and review of the original conception (Guba, 1990; Creswell, 2013a; Saunders et al., 2015; Johnson and Swedlow, 2021). The worldviews which are most referenced within research are (1) positivism; (2) constructivism, (3) transformative and (4) pragmatic. The positivism worldview is described as utilizing factual knowledge through empirical observation and measurement, with deterministic and reductionism (Creswell 2002, 2013a, 2013b). Under positivism the role of the observer is to act independent from study (Ihuah ad Eaton, 2013). The positivism world view adopts the quantitative research approach (Baker and Schaltegger, 2015; Klakegg, 2016). Positivism tends to rely on the authors experiences, where certain elements such as time and cause of events may not be determined by experiences alone. The constructivism worldview is described as adopting the position that no absolute truth exists, observing multiple participant observations and meanings (Creswell 2002, 2013a, 2013b; Easterby-Smith et al., 2008). Constructivism worldviews adopts qualitative research approach utilising observation of participants in real world settings uncovering social, cultural, and historical data on the research context (Creswell 2002, 2013a, 2013b). The transformative worldview is described as adopting the change-oriented position, observing change from a political, power and justice-oriented view (Creswell 2002, 2013a, 2013b; Mertens 2010). The pragmatic worldview is described as adopting the real-world position, observing several methods of data collection and data analysis to enable a systematic understanding (Creswell 2002, 2013a, 2013b; Baker and Schaltegger, 2015;

Saunders et al., 2015; Klakegg and Pasian, 2016). The pragmatic worldview adopts the mixed method research approach.

During the literature review stage, several worldviews were investigated in terms of (1) the authors personal experiences and initial industry consultation utilised aspects of positivism worldview via quantitative research approach, and; (2) the transformative worldview was described in terms of the changing political pressures resulting in the need to regulate chemicals to protect the environment, with (3) the pragmatic worldview shown in the complex nature of existing supply chain actors, relationship and data collection needs. Core to the research aim lies multiple sub-systems and processes within typical AD organisations which make the process of identifying chemical substances used within internally manufactured and supply chain sourced articles a highly complex scenario, requiring data collections across multiple other AD organisations acting as supply chain actors to other AD organisations, which in turns has the potential to expose potential business continuity risks. The pragmatic worldview being adopted across the remaining phases of the research study based on the multi-dimensional nature of the research context, aim and objectives.

3.3.3 Research Methods

Figure [3-4] presents a summary of the three main research methods quantitative, qualitative, and mixed methods. This research study utilizes mixed methods during the data collection phases to aid the development of a data model and identification of output reports to meet the research aim and objectives. Quantitative methods support the identification of internal and supply chain actors and their data requirements (data elements) which then defined within the data model, whilst qualitative methods enabled the identification of relationships, perspectives, and views between the different internal and external actors, supporting the identification of applicable output reports.

3.3.4 Research Methodology

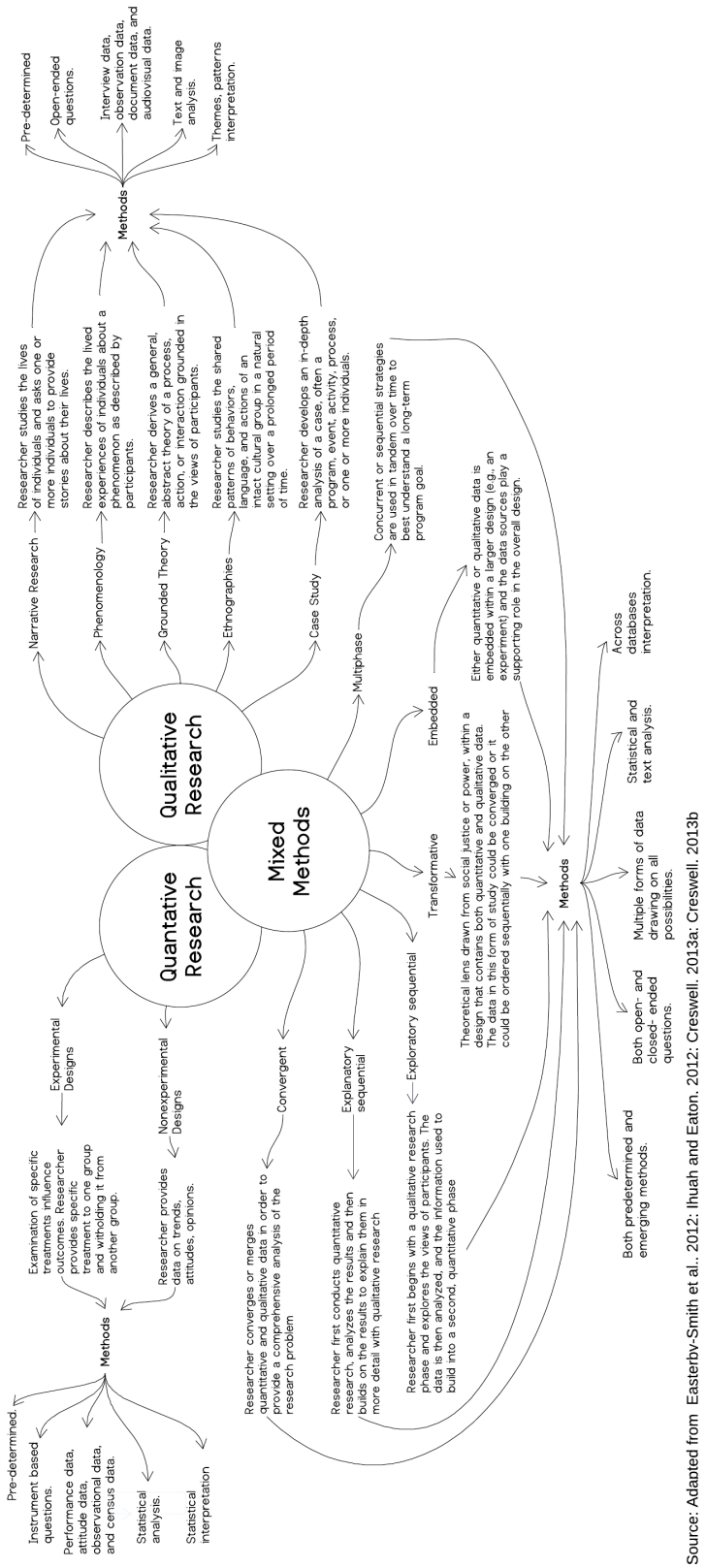
The selection of appropriate worldview and research methods influences the research strategy design and examination of the research problem, utilisation of the appropriate methodologies is vital in order to derive robust outcomes from the research study (Sahragard, 2004; Johnson and Clark, 2006). The research methodology defines how the research study

is to be planned and executed, encompassing the theories and models to be generated with subsequent testing (Reich, 1994).

3.4 Research Strategy

Figure [3-5] presents the high-level research strategy in term of the research aim, objectives and questions resulting in the generation of this thesis into five distinct phases:

1. *Introduction*: presented in chapter 1, establishing the research topic to be investigated outlining research aims, articulation of research problem, formulation of the research objectives and research questions.
2. *Literature Review:* presented in chapter 2, review of extant body of knowledge, identification of research gaps and determination of key research opportunities.
3. *Theoretical and Conceptual Development:* presented in chapter 3 and chapter 4, identification of the theoretical framework (current state) and conceptual framework (future state), which encapsulates the learnings and insights captured from this research study using the pragmatic worldview lens with the applicable mixed research methods.
4. *Data Collection, Analysis, and Interpretation:* presented in chapter 5, chapter 6 and chapter 7, verification of the data model and proposed system output reporting conducted via Delphi studies, validation of the proposed data model, via representative test data and applications (database and dashboard) to test data model and reporting, refinement of design based on outcomes, changing regulatory reporting requirements and expert feedback.
5. *Conclusion:* presented in chapter 8, summary of main research findings, examination of progress towards achieving research aims, objectives and questions, identification of future research activities.



Source: Adapted from Easterby-Smith et al., 2012: Ihuah and Eaton, 2012: Creswell, 2013a: Creswell, 2013b

Figure 3-4: Research Methods

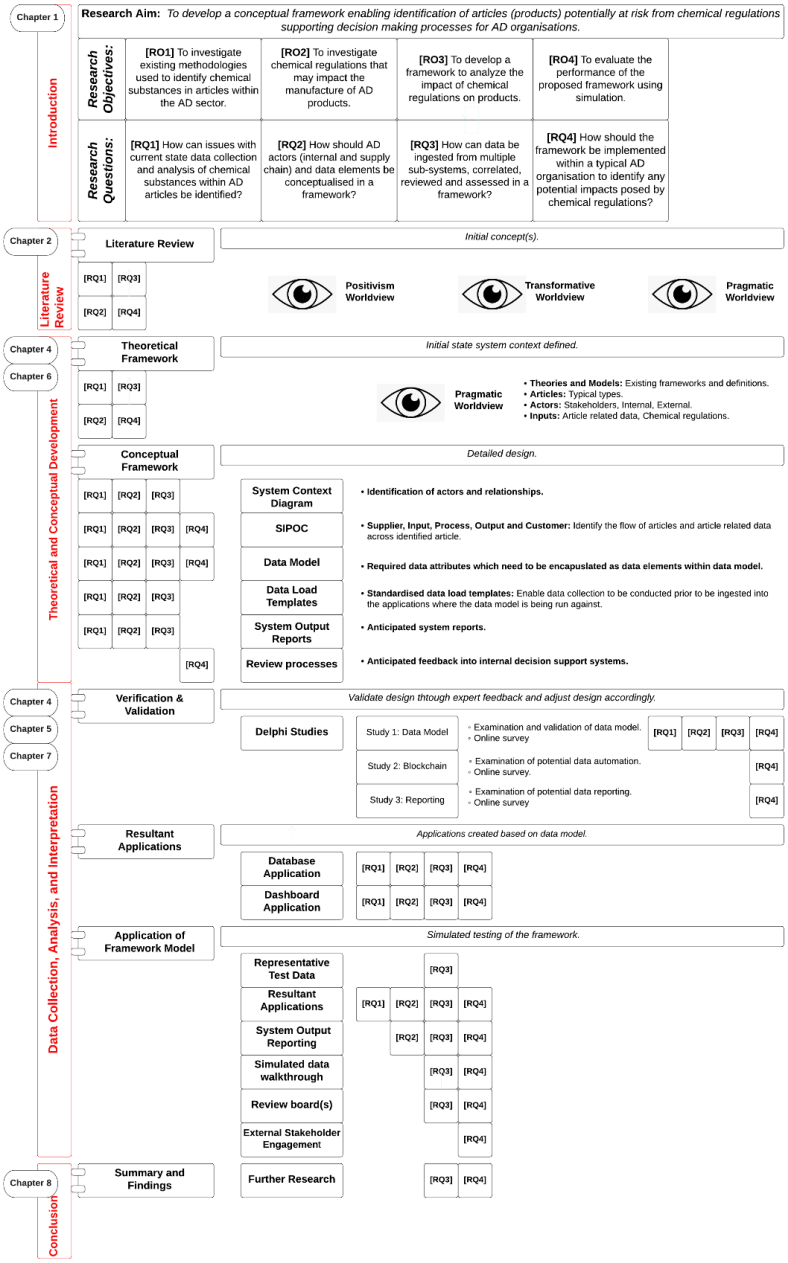


Figure 3-5: Research Phases, Questions and Objectives

3.5 Chapter Summary

This chapter presented the research methodology in terms of identifying the steps towards achieving the research aims, research objectives and questions. Key to the realisation of the research methodology was encapsulated in terms of the worldviews and research methods (Guba, 1990; Creswell, 2013a; Saunders et al., 2015; Johnson and Swedlow, 2021). The adopted pragmatic worldview was selected based on its flexible problem-centred approach to real-world problem of identifying regulated chemicals within articles used in the AD sector. In conjunction with the pragmatic worldview, the author adopted both Quantitative and Qualitative based research methods. Quantitative research methods were adopted to

identify actors, data requirements and data artefacts which in turn defined the data elements and subsequent data model, whilst Qualitative methods were adopted to investigate relationships between actors and support the development of applicable system output reports. Use of mixed methods was justified due to the complex nature of actors and articles within the AD supply chain, utilisation of both methods capitalised on the strengths of each method whilst mitigating the reliance on a single method. The definitions of the theoretical and conceptual frameworks have been provided, with key features and research relevance being demonstrated. Following the generation of the theoretical and conceptual frameworks, but prior to the data collection and data analysis phases, a deductive approach was adopted enabling the structure, guidance, and formality of the research to be applied into the existing body of knowledge. Finally, the use of simulation research enabled the solutions developed under the conceptual framework to be further verified and validated, via the; (1) utilisation of harmonised data load templates, with status values; (2) representative test data being applied to the harmonised data load templates; (3) the populated harmonised data load templates then being ingested via applications running the proposed data model, and; (4) the examination of output reports, and; (5) review boards examining the output reports and identifying applicable risk mitigation activities, and (6) where applicable solicitation of additional expert feedback. The overview of the Research Phases, Research Questions, Research Design & Methods, Outcomes and Outputs is presented in Table [3-1].

Table 3-1: Research Phases, Research Questions, Research Design & Methods, Outcomes and Outputs

Research Phase	Research Questions	Research Design and Methods	Outcome	Outputs
Literature review.	[RQ1], [RQ2], [RQ3], [RQ4].	Systematic literature review, Initial industry consultation.	Key concepts for the research study including current state industry practice for data collection from internal systems and data collated from the supply chain, identification of chemical substance(s) reportable against different chemical regulations. Initial industry consultation expanded author knowledge from which qualitative data collected through interviews supported the design of the quantitative data to be collected via Delphi study questionnaires. Identification of synergies, interrelationships and issues identified. Gaps in literature evidenced.	*Conference papers* • Supply chain material compliance reporting paper presented at IEOM. Ref: Takhar and Liyanage (2017a). • Chemical reporting system for manufacturing companies presented at ICMR. Ref: Takhar and Liyanage (2017a). • Pricing, EPR, Sustainability and Circular Economy paper presented at AICBEM. Ref: Takhar and Liyanage (2018a). • Impact of Industry 4.0 on Supply Chains and Sustainability presented as OSCM. Ref: Takhar and Liyanage (2018c).
Theoretical framework development.	[RQ1], [RQ2], [RQ3], [RQ4].	Construction of theoretical framework.	Relevant actors, internal and external systems), approaches, processes and data elements assessed for theory building. Theoretical framework constructed.	*Conference papers* • Framework for a Chemical Reporting System paper presented at ICITM. Ref: Takhar and Liyanage (2018b). • Blockchain application in supply chain chemical substance reporting paper presented at CIMS. Ref: Takhar and Liyanage (2018d). • Understanding implications of Chemical Regulations, Circular Economy and Corporate Social Responsibility for Product Stewardship presented at ICMR. Ref: Takhar and Liyanage (2019a). • Value chain impacts of EU WFD as a result of reporting SVHCs presented at CIMS. Ref: Takhar and Liyanage (2019b). *Journal paper*

Research Phase	Research Questions	Research Design and Methods	Outcome	Outputs
				• The Impacts of Sustainability, Extended Producer Responsibility, and the Circular Economy on Product Pricing models. Pricing models published in IJCMR. Ref: Takhar and Liyanage (2019).
Conceptual framework development	[RQ1], [RQ2], [RQ3], [RQ4].	Construction of conceptual framework.	Conceptual framework developed. Early state data model of data elements captured. Roadmap of activities to develop diagnostic applications to support implementation of conceptual framework.	*Journal paper* • Framework for a Chemical Substance Reporting System. Published in ATESJ. Ref: Takhar and Liyanage (2018).
Data collection, analysis, and interpretation.	[RQ1], [RQ2], [RQ3], [RQ4].	Verification and validation.	Delphi studies with applicable expert user groups investigated the data model, automation via blockchain and output reporting. Mixed-method design using online surveys including quantitative (closed-loop questions, Likert scales) and Qualitative (open-ended questions).	*Journal papers* • Blockchain application in supply chain chemical substance reporting a Delphi study. Published in OSCM. Ref: Takhar and Liyanage, (2021a). • Realignment of Product Stewardship towards Chemical Regulations, the Circular Economy and Corporate Social Responsibility – a Delphi Study. Published in OSCM. Ref: Takhar and Liyanage, (2021b).
	[RQ1], [RQ2], [RQ3], [RQ4].	Application(s).	Simulation research. Application of the framework using data model and representative data. Representative test data constructed via industrial observations.	*Research Outputs* • Data model. • Harmonised data collection templates to collate data and set reporting status. • Application 1: MS-Access database ingesting data load templates and providing diagnostic reporting to support framework. • Application 2: Dashboard application ingesting data load templates to provide visualisation on data. • Supplier risk assessment developed to aid internal decision making. • Review boards, analysing data and performing risk mitigation analysis.

Research Phase	Research Questions	Research Design and Methods	Outcome	Outputs
Extended research.			Future research.	*Industry Research Paper* • Supply Chain Traceability of Substances of Concern Across the Electronics Sector Supply Chain, written for IPC. Ref: Takhar (2019). *Journal Paper* • Transforming product labels using digital technologies to enable enhanced traceability and management of hazardous chemicals published in IJSCOR. Ref: Takhar and Liyanage (2021c). *UK Parliamentary Office of Science and Technology paper (contributor).* • Regulating Product Sustainability. Ref: UK POST, (2021).

Chapter 4: Conceptual Framework Design

4.1 Introduction

This chapter presents the proposed conceptual framework design. The structure of this chapter is shown in Figure [4-1].

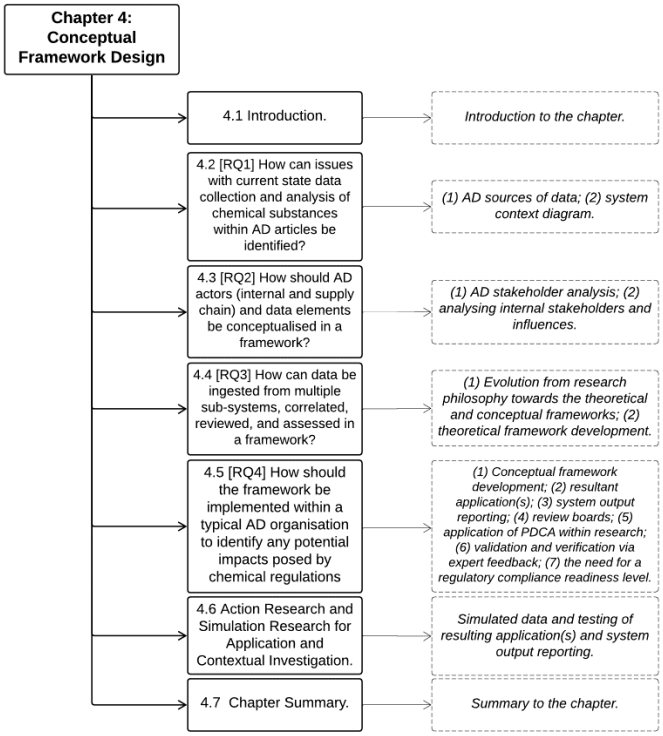


Figure 4-1: Chapter 4 Structure

4.2 [RQ1] How can issues with current state data collection and analysis of chemical substances within AD articles be identified?

AD sources of data are shown in section 4.2.1. A system context diagram is shown in section 4.2.2.

4.2.1 AD Sources of Data

This section examines the sources of data, that need to be ingested into the envisaged data model, based on the identification of actors, actor roles, articles provisioned, and applicable technical design authority, responsible for the article definition(s).

4.2.1.1 Internal Definitions

Table [4-1] defines the initial set of AD article definition data sources assumed in the theoretical framework design.

Table 4-1: Assumed Article Definition Data Sources

Area	Data Type	Data description
Maintenance.	Technical Publication Manuals.	Define where AD components are installed and de-installed within an Aircraft structure. The technical publication manuals will reference a unique position for a given article which may be supplied from multiple suppliers.
Sales.	As Shipped Article data.	ERP / sales system's data on articles as sold, where it is common for the as sold part numbers as sold to be different from internal part numbers.
Manufacturing.	As Built Article data.	Optional additional internal product related data, depicting any changes to a part revision / version, covering possible design changes and different chemical substances, mixtures and materials used in a manufacturing cycle.
Definition.	As Defined Article data.	BOM structure for articles depicting all lower-level articles contained within a complex article structure.
Definition.	As Designed Article data.	Article number, article name, geometry drawing data, reference standards and specifications.
Definition.	Geometry drawings(s).	Unique geometry for a given article number, referencing applicable industry standards, material, and process specifications as well as any unique chemical substances, mixtures and materials defined against an article number.
Definition.	Standard(s).	Industry standards for standard material types which call out chemical composition data, often in ranges of formulation.
Definition.	Specification(s).	Specifications which define chemical substances, mixtures and materials which appear on finished article or are used in the process of article manufacture.

4.2.1.2 Sources of Substance Related Information in AD Articles

Table [4-2] depicts product related data sources to be utilized within the conceptual framework design.

Table 4-2: Sources of Substance Related Information in AD Articles

Ranking	Data Source	Data Usage	Data Accuracy and Consistency
One.	Geometry Drawings.	Define the Article fit, form and function of an article, traditionally referencing related material and process specifications.	Depends on the age of the article, where legacy articles are likely to be defined in legacy 2D PDM formats, whilst newer articles are likely to be defined in 3D PLM formats. Care needs to be paid to the revision, lifecycle status and version history of earlier article versions.
Two.	Material / Process specifications.	Material specifications define the chemical substances, mixtures and materials which appear on the finished article. Process specifications define the chemical substances, mixtures and materials are used to manufacture an article, but do not appear on the finished article.	Material and Process specifications are typically managed in Material Database systems.
Three.	Supplier Material Declarations.	Data collected during a supply chain material declaration request process. The defined reporting for the AD sector is IPC-1754 format (originally defined by the author).	Confirmation from a supplier, regardless of the supplier being a technical design authority or not, confirming if any chemicals of concern exist on the finished article(s) provisioned by a supplier.

Four.	Supplier Compliance Statements.	Generic statements defining compliance to a specific regulation, but not necessarily identifying any hazardous chemical substances. To be reviewed and then potentially extracted.	
Five.	Industry Standards.	Define chemical substances, mixtures, and materials for industry standard articles such as nuts, bolts, washers, etc. The use case is where an OEM does not define the precise chemical composition for a given component, relying on the component manufacturer to produce the component(s) to an industry standard.	

4.2.1.3 Core Chemical Regulation Reportable Substance Lists

Table [4-3] defines the core reportable substance lists defined in chemical regulations that impact the AD sector.

Table 4-3: Core Chemcial Regulation Reportable Substance Lists Applicable to AD sector

Data Source	Data Usage
Chemical regulation declarable substance lists.	• Define a regulatory reporting requirement against a declarable substance list for a given chemical regulation: o US TSCA Chemical Inventory - Active substances / Inactive substances (TSCA, 2020). o ECHA Chemicals Universe (ECHA, 2019c). o EU Registration, Evaluations, Authorisation, and restriction of CHemicals (REACH): Candidate List; Annex XIV, Annex XVII, Nanomaterial Annexes (EC, 2006a; ECHA, 2020a, ECHA, 2020b; ECHA, 2020c). o EU Restriction of Hazardous Substances (EU, 2003; EC, 2011; EU, 2015). o US CMR (SEC, 2012). o EU CMR (OECD, 2019). o Critical Raw Materials (EU, 2017a; US Gov, 2017; USGS, 2018; Takhar 2019a). o EU Radioactive Substances (EU, 2013). o SIN list (Chemsec, 2020).
AD Trade Association DSL.	• The IAEG AD-DSL (IAEG, 2019) is as the AD sector declarable substance list, adopted by the leading AD sector companies which is updated on an annual basis.

Note – As updates occur to the declarable substance lists above, changes will be reflected within the proposed data model.

4.2.2 System Context Diagram

A System Context Diagram (SCD) presented in Figure [4-2] to show the pre-Delphi study initial system view, in terms of actors, inputs and outputs, enabling the identification of

relationships (Kossiakoff et al., 2011). A SCD enables the scope of the investigation to be outlined and agreed, prior to further detailed investigation activities.

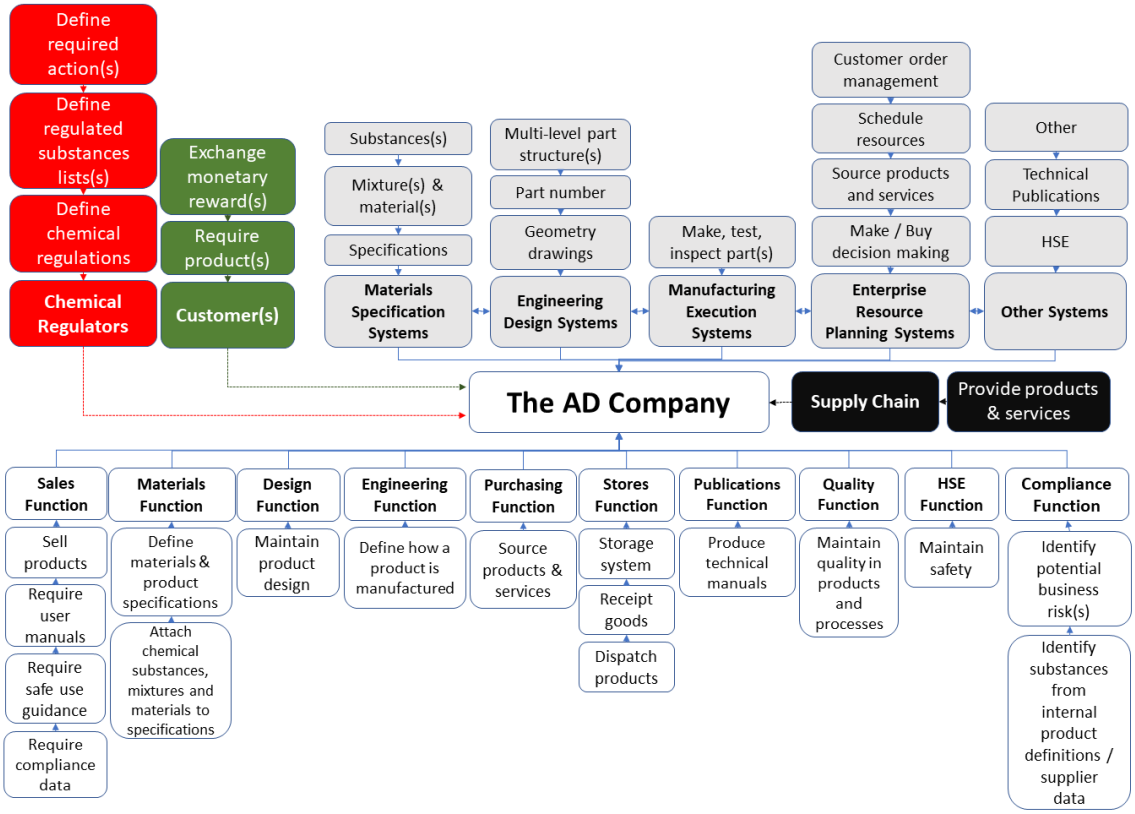


Figure 4-2: System Context Diagram for a Typical AD Organisation

4.3 [RQ2] How should AD actors (internal and supply chain) and data elements be conceptualised in a framework?

4.3.1 AD Stakeholder Analysis

This section extends the analysis shown in Figure [4-2] by examining AD sector specific, supply chain relationships.

4.3.1.1 AD Technical Design Authority

An AD Technical Design Authority (TDA) is responsible for the design of a given article, stipulating the geometry (fit, form and function) on an article, as well as providing the definitions of substances, mixtures and materials used to manufacture the article. As noted in the literature review, issues arise where the TDA has over defined several additional substances, mixtures, and materials as either mandatory or optional substances, which necessitates the need to perform supply chain data collection and reporting to confirm the exact substances, mixtures and materials utilised by a supplier to produce AD articles. Table [4-4] depicts the TDA types and anticipated activities.

Table 4-4: AD Sector Technical Design Authority Types

	Chemical substances, mixtures, and materials	**Standard articles (parts)**	**Supplier defined**	**Build to print suppliers**	**Build to specification supplier**	**Sharing supplier**
Supplier and article types.	Chemical extractors, manufacturers, refiners, formulators, mixers.	Semi-components, components, articles manufacturers.		Semi-components, components, articles, and assemblies' manufacturers.		
Technical design authority: responsible for the design of articles(s).	Supplier responsible.	Supplier responsible for design of articles.	Supplier responsible for design and selection of materials.	Produced by supplier to buyer specifications.	Produced by supplier to buyer specifications, with flexibility on material selection.	Shared design, manufacturing costs and profits.
Design changes / selection of materials.	Supplier responsible.	Supplier builds to industry-standard specifications.	Supplier informs buyer of any hazardous chemicals.	Supplier informs buyer of any hazardous materials. Changes must be approved.		Shared between buyer and supplier. Supplier informs buyer of any hazardous chemicals. Changes must be approved.
Likelihood of data variance: ill-defined specifications calling out multiple options for substances, mixtures, and materials.	Less likely to see variance as chemical substances, mixtures and materials are generally well defined.	Low variance expected in standard component and articles.	Variance is expected, dependent on configuration management controls within an organisation, for example if material specifications allow for optional matters, mixtures, or materials.			
Data provision: at the chemical composition level.	Safety data sheets, compliance statements.	Compliance statements, reporting against data exchange standards dependent on the industry sector.				

4.3.1.2 Assumed AD Specific Stakeholders [Pre-Delphi]

Table [4-4] and Figure [4-3] detail the initial state stakeholder groups, stakeholders, and stakeholder role(s).

Table 4-5: Assumed AD Specific Stakeholder Groups, Stakeholders, and Roles [Pre-Delphi]

Stakeholder group	**Stakeholder name**	**Stakeholder role(s)**	**Data provided by stakeholder(s)**
End users.	• End consumers.	• Desire articles that are: (i) safe; (ii) free from hazardous substances; (iii) do not impact the environment.	
Investors / lenders.	• Shareholders. • Banks / private lenders. • Others.	• Desire organisation to perform on a financially sound basis, generating yearly increasing profit returns.	

Stakeholder group	**Stakeholder name**	**Stakeholder role(s)**	**Data provided by stakeholder(s)**
Internal functional areas.	• Employees.	• Fair income and safe working environments	
	• Finance function.	• Ensure organisation has more money coming in, than expenditure.	• Financial accounts showing financial stability.
	• Human resource's function.	• Manage employee relationships.	
	• Materials function.	• Define chemical substances, mixtures and materials which can be used to design and manufacture articles.	• Materials and process specifications
	• Research and Design function (R&D).	• Design articles fit for purpose which can be manufactured.	• Geometry drawings referencing materials and process specifications.
	• Engineering design function.		
	• Purchasing function.	• Procure materials for the organisation, potentially encompassing manufacture internally (make) or outsource manufacture (buy) decisions.	• Purchase order details: supplier name, supplier code, internal article numbers, supplier article numbers, date of last order, quantity, etc.
	• Manufacturing function.	• Manufacture articles using geometry drawings and defined materials.	• Manufacturing instructions.
	• Testing function.	• Test the article meets required functional design and safety parameters.	• Test specifications and programs.
	• Sales and marketing function.	• Health and safety function.	• Sales materials.
	• Quality function.	• Ensure articles are manufactured to be safe and of high quality.	• Define internal policies and procedures.
Authorities.	• Local. • Regional. • National. • International.	• Define rules and norms. • Actions dependent on political motives. • Trade-off between economic prosperity and environmental actions. • Define chemicals of concern. • Require industry to identify data on the use of chemicals of concern. • Perform enhanced market surveillance.	• Define regulatory landscape (product / safety / chemical regulations). • In terms of chemical regulations provide lists of chemicals under scope. • Specific to the AD sector EASA, FAA and CAA define airworthiness certifications.
Supply chain tiers (specialist processes).	• Heat. • Plating. • Bonding. • Finishing.	• Specialist processing operators who provide heat treatment, shot peening, bonding, plating, and finishing treatments such a paint, livery, polishing, etc.	• Specialist processors tend to conform to specific customer requirements / industry standards. • Specific chemical substance information will generally need to be requested from the specialist processor.

Stakeholder group	**Stakeholder name**	**Stakeholder role(s)**	**Data provided by stakeholder(s)**
Supply chain tiers (raw materials and articles).	• Chemical extractors / manufacturers.	• Chemical mining and man-made chemical substance manufacturing.	• SDS data in terms of reporting hazardous and regulated chemical substance information as of a given publication date.
	• Chemical refiners / formulators.	• Process chemical substances. • Define mixtures (2 or more chemical substances).	
	• Mixture and material manufacturers.	• Manufacture chemical mixtures and materials derived from chemical substances.	
	• Chemical distributors.	• Distribute chemical substances, mixtures, and materials.	
	• Semi-component manufacturers. • Component manufacturers. • Article manufacturers. • OEMs.	• Collect data on chemicals of concern used within articles. • Identify any regulated chemicals from article sources from the supply chain. • Identify any regulated chemicals for products defined and manufactured internally. • Analyse any hazardous chemical substances identified and take the appropriate risk management measures. • Provide data to downstream users.	• Compliance statements (online). • Compliance statements in technical publication manuals. • Compliance statements via data exchange standards (IEC, IPC, ISO, etc.) • Ad-hoc statements when data requests made by customers.
Article Distribution.	• Transportation.	• Transport AD articles.	• Appropriate labelling and packaging for AD Articles. • Identification of any hazardous and regulated chemicals.
	• Distributors.	• Distribute AD articles.	
	• End users.	• Airframe manufacturers. • Aircraft lessors. • Airline operators.	
Maintenance.	• MRO shops.	• Repair and renew AD articles to the latest standard. • Perform work in-house or outsource from the supply chain.	• Information on chemical substances used in the repair of used AD articles. • Need to provision this data to clients who have used their services.
EOL AD Articles.	• Waste stream operators.	• Identify hazardous chemicals in EOL AD articles. • Do not repair / renew EOL AD articles as this is done by the MRO shops • Repurpose EOL AD articles into new uses. • Recycle materials from EOL AD articles.	• Need to provision data on hazardous chemicals to clients who have used their services
Trade Association(s).	• AD manufacturer specific.	• Collaboration with other stakeholder(s) within the same industry sector. • Identify potential industry level issues, develop collaborative reportable substance lists, lobby regulators, governments, etc.	• IAEG AD-DSL – declarable substance list generated for the AD sector.
Competition.	• Competitor(s).	• Compete on price, quality of articles.	• Will promote the environmentally friendly credentials of their own articles over competitor articles.

Stakeholder group	Stakeholder name	Stakeholder role(s)	Data provided by stakeholder(s)
Civil society	• NGOs.	• Ensure safer, fair, equal, and ethical society if available to all.	• Highlight issues to the local communities, media, regulators, regulators, governments, consumers, and the public.
	• Trade unions.	• Protect worker rights	
Media	• Newspapers.	• Highlight issues to the public relating to the AD sector, articles, and AD organisations.	
	• Journals.		
	• Online publications.		
	• Television and satellite service providers.		

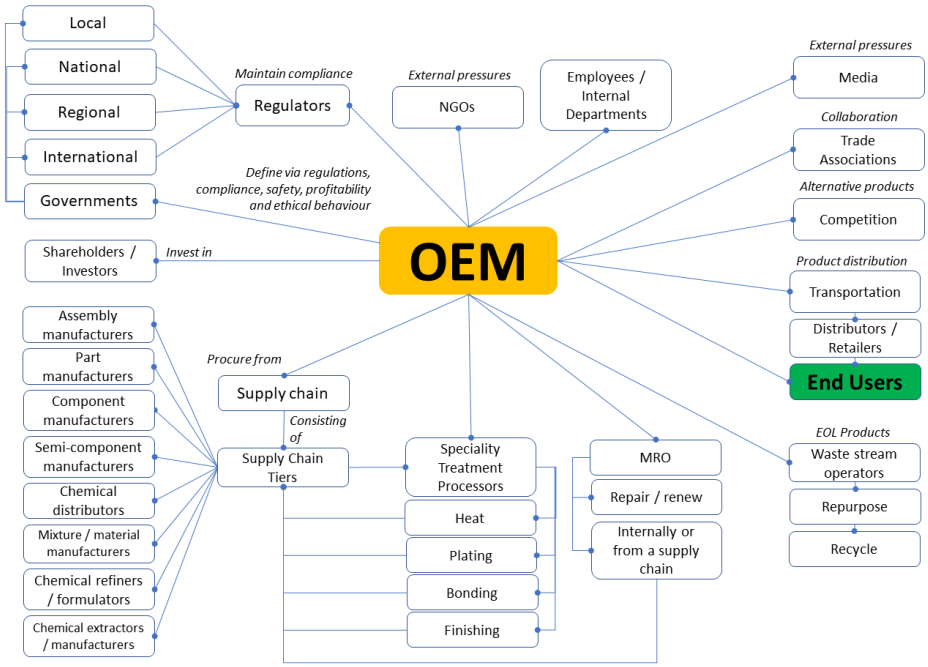


Figure 4-3: Assumed AD Stakeholders (pre-Delphi)

4.3.1.3 Analysing AD Internal Stakeholders and Influences

Using the internal and external AD stakeholders identified in Table [4-4], a scanning responsibility matrix (Mendelow, 1983) was generated as shown in Table [4-3], where relationships are identified in terms of (i) R = responsible and C = contribute. Where chemicals of concern are identified to a given chemical regulation, to a given AD article, facilitates the need to examine stakeholder in terms of influence and power, this was undertaken using the Mendelow Matrix (Mendelow, 1983; Mendelow, 1991; Schmeer, 1999; Varvasovszky and Brugha, 2000) methodologies examining levels of interest against power / influence of the stakeholder, with applicable stakeholder management defined as: (1) monitor; (2) keep informed; (3) keep satisfied and (4) manage closely. Figure [4-6] depicts the generated Mendelow Matrix.

Table 4-6: Scanning Responsbility Matrix

	Investors	Investors / Lenders	Employees	Authorities	Suppliers: materials / articles	Suppliers: processes	Product distribution	End consumers	Waste stream operators	Competition	Trade associations	Civil society (NGOs)	Media
Chief Executive Officer	R			R					R	C	C	C	C
Financial function	C	R											
Human resource function			R										
Materials function				C	R	R	R		C		C		
Engineering design function (R+D)				C	C	C	C	R	C		C		
Purchasing function				C	R	R	R	C	C		C		
Manufacturing function				C	C	C	C	C	C		C		
Testing function.					C	C	C	C			C		
Sales and marketing function								R				R	R
Quality function					C	C	C	C	C		C		

Source: Adapted from Mendelow, 1983.

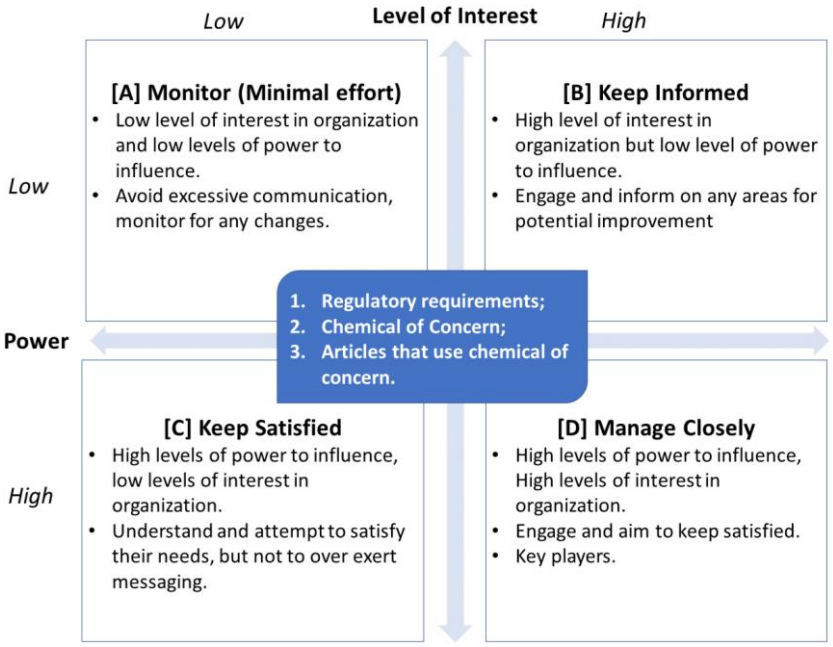


Figure 4-4: Mendelow Matrix Applied to Reseacrh Context

Source: Adapted from Mendelow, 1983; Mendelow, 1991; Schmeer, 1999; Varvasovszky and Brugha, 2000.

4.4 [RQ3] How can data be ingested from multiple sub-systems, correlated, reviewed, and assessed in a framework?

4.4.1 Evolution from Research Philosophy, Towards the Theoretical and Conceptual Frameworks

Figure [4-5] depicts the evolution from the research philosophy, through to the theoretical framework that underpins this research, through to the development of the conceptual framework.

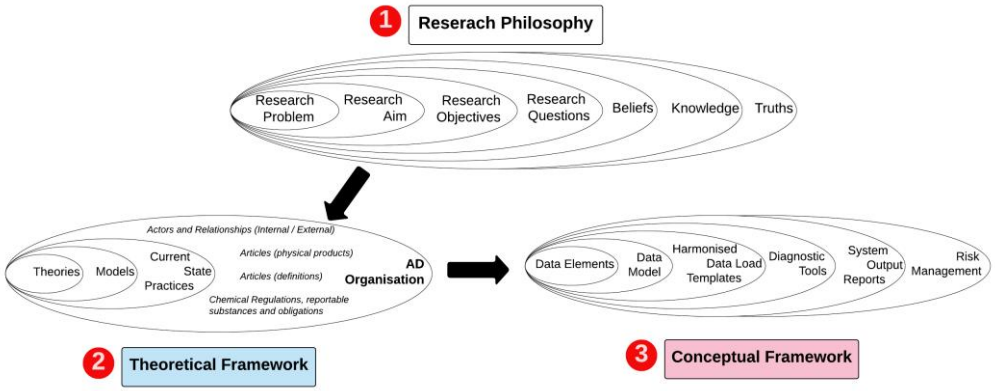


Figure 4-5: Research Philosophy, Theoretical and Conceptual Frameworks

4.4.2 Theoretical Framework Development

The theoretical framework identifies the foundation upon which the observed theories, models, propositions, actors and actor relationships, data and analysis, can be derived, enabling the identification of current state behaviours and traits (Sutherland, 1975; Weick, 1989; Imenda, 2014; Adom et al., 2018). The theoretical framework identifies the anticipated actors who will interact with the framework and the data elements that form the basis of the proposed data model. The initial theoretical framework is shown in Figure [4-6].

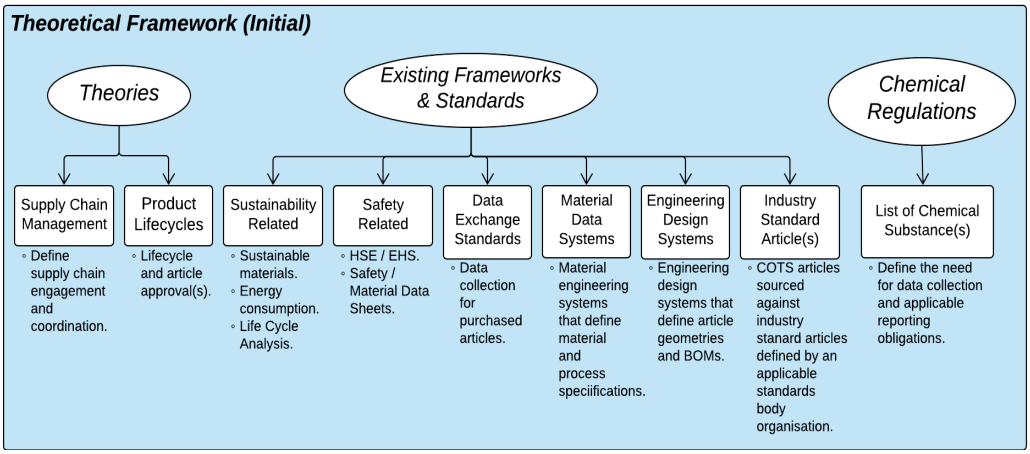


Figure 4-6: Initial State Theoretical Framework

To support the extraction of data from multiple source systems and data formats, harmonised data load templates will be generated to support data collection activities from applicable internal sub-systems and external actors. The developed theoretical framework is shown in Figure [4-7].

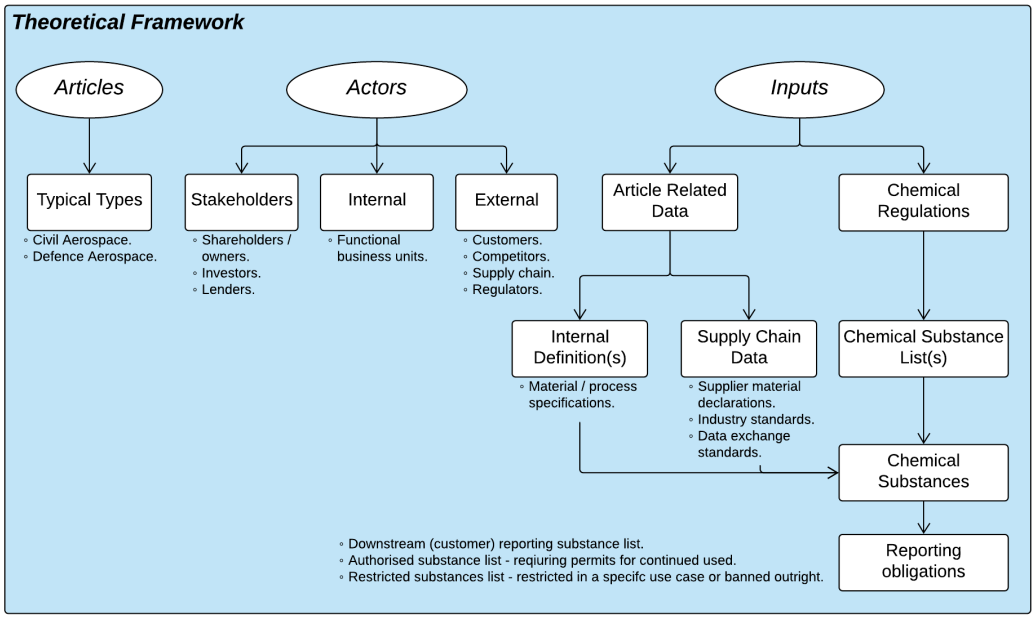


Figure 4-7: The Developed Theoretical Framework

4.5 [RQ4] How should the framework be implemented within a typical AD organisation to identify any potential impacts posed by chemical regulations?

This section explores the conceptual framework development phase. Conceptual framework development is shown in section 4.5.1. Resultant application(s) are discussed in section 4.5.2. System output reporting is discussed in section 4.5.3. Review boards are discussed in section 4.5.4. The use of the Plan-Do-Check-Act cycle are shown in section 4.5.5. Validation and verification through expert feedback is shown in section 4.5.6. The need for a regulatory compliance readiness level is discussed in section 4.5.7.

4.5.1 Conceptual Framework Development

Theoretical frameworks can be described as encapsulating a 'whole theory' perspective, whereas the conceptual framework attempts to develop a more focused scope applicable to the research study (Imenda 2014; Adom et al., 2018). The conceptual framework, in the context of this research study, extends upon the theoretical framework by proposing tasks and actions, where the actors using the conceptual framework may then interact with the data model, in terms of data ingestion, review and analysis of potential risk mitigation

actions. The data load templates generated from the theoretical framework will form the basis of the of data model to be encapsulated within the conceptual framework, from which further data analysis identifies potential risks posed by chemical regulations. The conceptual framework is shown in Figure [4-8].

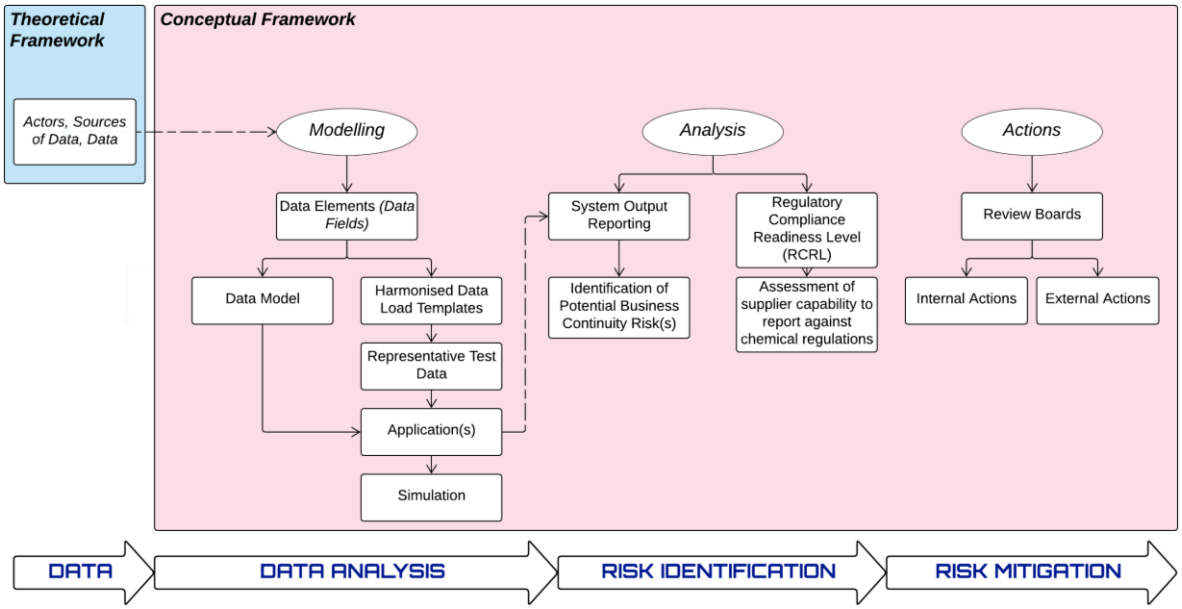


Figure 4-8: Conceptual Framewok Design

Table [4-7] defines a high-level task list of activities to follow in the development process of the conceptual framework.

Table 4-7: Conceptual Framework High-Level Task List

#	Task name	Task description	Expected phase
1.	Initial framework requirements list.	Identification of initial requirements list.	Pre-literature review.
2.	Identification of stakeholders.	Stakeholder analysis will need to be undertaken to identify the relevant actors, roles that will interact with the proposed impact framework.	Literature review, Delphi studies, conference / journal papers, conceptual framework.
3.	Identification of initial stakeholder value mapping.	Stakeholder analysis identifying value in terms of value stream mapping, stakeholder influence mapping.	
4.	Identification of initial risk register.	Identification of risks that exist for an organisation because of chemical regulations.	Literature review, Delphi studies, conceptual framework.
5.	Update framework requirements list.	Update framework requirements list.	
6.	Identification of applicable chemical regulations and reporting standards.	Identify regulations and reporting standards which need to be adhered to by the AD sector.	Literature review.
7.	Identification of chemicals of concern.	Chemical substances listed under chemical regulations which impact the AD sector.	
8.	Supplier on-boarding activities.	Identification of activities when a supplier is first introduced into an organisation, specifically investigating requirements for supply chain chemical substance reporting.	Literature review, Delphi studies.
9.	Update stakeholder mapping.	Update stakeholder mapping.	Literature review, Delphi studies,

#	Task name	Task description	Expected phase
10.	Identification of data sources.	Identification of data sources to be used.	conference / journal papers, conceptual framework.
11.	Current state data collection.	Investigation of current state supply chain chemical substance reporting.	
12.	Validate theoretical framework assumptions.	Delphi study review of data model.	
13.	Identify potential automated data collection methodologies.	Identification of automated methods of data collection utilising blockchain technologies via a Delphi study	
14.	Examine system output reporting.	Delphi study on reporting.	
15.	Update risk register.	Review and update risks that exist for an organisation because of chemical regulations.	
16.	Update framework requirements list.	Update framework requirements list.	
17.	Generate software development documents.	Create software development documentation covering CMMI level 1 and ITIL software library. Documentation includes requirements traceability matrix, configuration management, database design, software testing and release documents.	Conceptual framework, detailed design, application of data model and findings.
18.	System output reporting.	System output reports designed and tested to ensure the framework generates data required as feedback into internal decision-making systems.	
19.	Application of Stakeholder influence mapping.	Stakeholder influence mapping helps to identify stakeholder perspectives, to be adopted in the event of a specific chemical substance resulting in business continuity risks.	
20.	Update risk register.	Review and update risks that exist for an organisation because of chemical regulations.	
21.	Finalize documentation.	Update required documentation including a review of the implementation.	

Key elements of the conceptual framework design are: (1) resultant applications; (2) system output, and; (3) review boards, as discussed below:

4.5.2 Resultant Application(s)

Two applications are proposed within the conceptual framework to ingest and analyse data in relation to assessing the impact of chemical regulations against AD articles.

4.5.3 System Output Reporting

System output reporting enables the identification of risks posed by chemical regulations in the context of AD articles. The system output reporting shall utilise data ingested into the data model, cross referencing chemical substances used on their own, within mixtures and materials identified from internal and external actors against applicable chemical regulation substance lists, where AD organisation internal actors would perform logical assessments as to whether a given chemical substance is present and reportable against a given chemical regulation.

4.5.4 Review boards

To support AD organisational processes, internal functional review boards are outlined to enable the AD organisation to perform additional risk mitigation activities, in terms of assessing the business risks posed by a given chemical substance being regulated under a chemical regulation, such actions may include investigation of: (1) article reformulation and testing by substitution of a given chemical substance, and / or; (2) justification the use of a chemical substance, to be applied in the event of a chemical substance being further controlled under a given chemical substance.

4.5.5 Application of Plan-Do-Check-Act Methodology Within Research

Utilisation of the Plan-Do-Check-Act (PDCA) methodology as defined in quality control systems, was applied throughout the five key phases of research study, as a means of reviewing the research outputs in an iterative manner to bring about continuous improvements and refinements (Deming, 1986., Figure [4-9] shows how the PDCA methodology was applied in the context of this research study, in terms of investigation of the solutions developed as part of the conceptual framework, from conception, modelling, testing followed by identification issues and concerns which were then further reviewed and developed as incremental continuous improvement activities under the PDCA cycle.

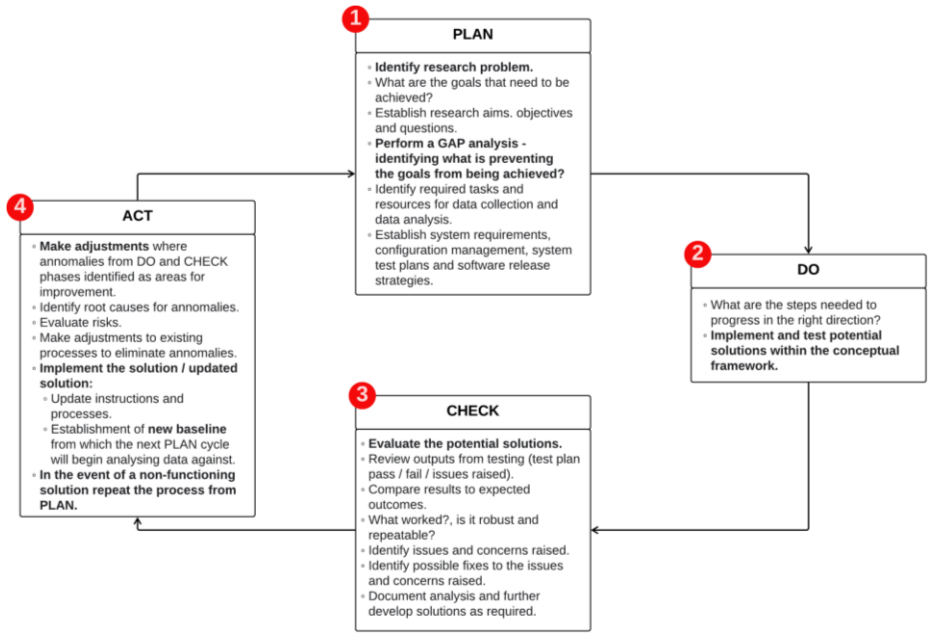


Figure 4-9: Application of PDCA Cycle Within the Reserach Study
Adapted from Deming, 1986.

Use of the PDCA cycle, supported the continuous improvement activities undertaken within the research study, enabling confirmation of the design of the theoretical and conceptual framework propositions, to ensure the implemented solutions were robust and repeatable.

4.5.6 Validation and Verification Through Expert Feedback

The use of expert engagement within the research study is a critical component. The use of expert feedback enables the researcher to ascertain the reasonableness, accuracy, robustness and repeatability of the proposed theoretical and conceptual frameworks, especially where limited existing knowledge exists with sparse or non-existent data (Landry et al., 1983; Meyer and Booker, 1991; Baker and Schaltegger, 2015; Saunders et al., 2015). Expert engagement offers significant advantages over utilisation of non-expert engagement, most significant of which enables an enhanced assessment of the propositions presented to participants.

4.5.6.1 Validation and Verification of Frameworks via Delphi Studies

Validation and verification of the proposed theoretical framework is to be undertaken eliciting expert user feedback in the form of a Delphi study, utilising group decision techniques in which a series of questions related to the data model are posed, where consensus amongst the Delphi study members, then informs the author of any remedial actions that may need to be undertaken (Okoli and Pawlowski, 2004). Expert feedback was captured in this research study via: (1) initial industry consultation identifying key participants from the AD sector who agreed to participate in the three Delphi studies as industry sector experts; (2) based on the specific Delphi study being undertaken, experts were selected based on (i) academia based on searching for relevant research papers and identifying lists of academic experts; (ii) based using internet searches to identify media experts who have published a number of media articles on the given Delphi study topic; (iii) industry experts identified from initial industry consultations and from request for participation in AD trade association engagements; (iv) topic related industry consultant experts identified from internet searches. Detailed Delphi methods selection, data collection and analysis for each of the three Delphi studies are shown in Chapter 5. Figure [4-10] frames the use of expert engagement and feedback in terms of development of the theoretical and conceptual frameworks.

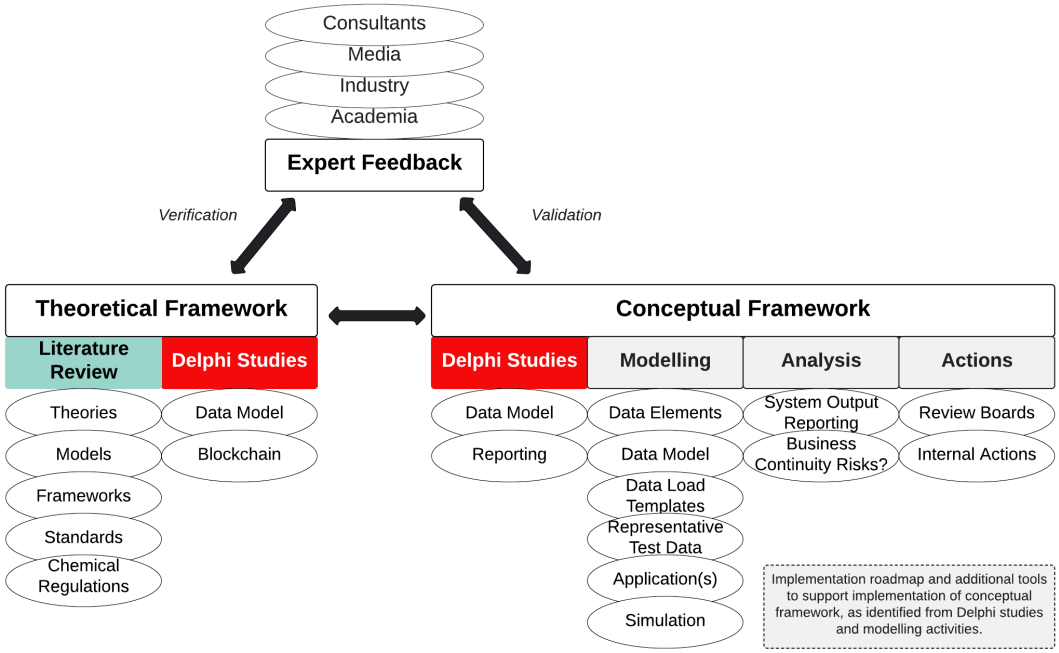


Figure 4-10: Verification and Validation Utilising Expert Feedback

4.5.6.2 Verification

Verification plays a pivotal role in ensuring the outcomes from the conceptual framework meet the desired research objectives. Verification entails checking, confirming completeness, identifying errors, and performing associated error corrections (Morse et al., 2002). Core to this research study is (1) the identification of data artefacts (data elements / fields) which form; (2) a data model against which; (3) harmonised data load templates will be utilised to ingest data, which; (4) in turns generates system output reporting to highlight potential business continuity risks. Verification of the developed theoretical and conceptual frameworks occurred continuously as the research study evolved: (1) from previous experiences in developing data exchange standards to enable industry data reporting, defining a base list of a data elements to exchange data on procured articles, additionally; (2) expansion of data elements to include data elements that identify internally manufactured article information, in addition to supply chain data captured in (1); (3) initial industry consultation interviews which further expanded the data elements; (4) Delphi studies examining: (a) the data model in depth; automation of data collection via smart contracts and blockchain digital ledger reporting; (c) output reporting; (5) data load templates for ingesting data into the system; (6) emerging new data elements from resultant regulatory changes (EU SCIP database and UK Brexit). Use of expert feedback comments was not limited to the development of the theoretical and conceptual frameworks, the feedback comments were also used to formulate the requirements and test scripts for the applications developed as part of the research.

4.5.6.3 Validation

Following verification of data correctness, validation entails ensuring the implemented design meets the intended purpose of solving a problem situation for the intended user in a manner which forms a repeatable process (Landry et al., 1983). Validation occurred within the research study via the use of action research and simulated data explored in the next section.

4.5.7 The Need for a Regulatory Compliance Readiness Level (RCRL)

Section 2.5.2 examined industry readiness levels as a method of assessing internal and external maturity levels pertaining to manufacturing capabilities, systems, procedures, and processes. The literature review highlighted the need to either extend existing industry readiness level assessments to include regulatory compliance reviews or generate a new readiness level in line with the aims and objectives of this research study. A high-level Regulatory Compliance Readiness Level (RCRL) will be developed as part of the detailed design section to support an onboarding assessment of a supplier's existing regulatory compliance reporting capabilities, using specific criteria levels and a scale to show potential maturity levels, as shown in Figure [4-11].

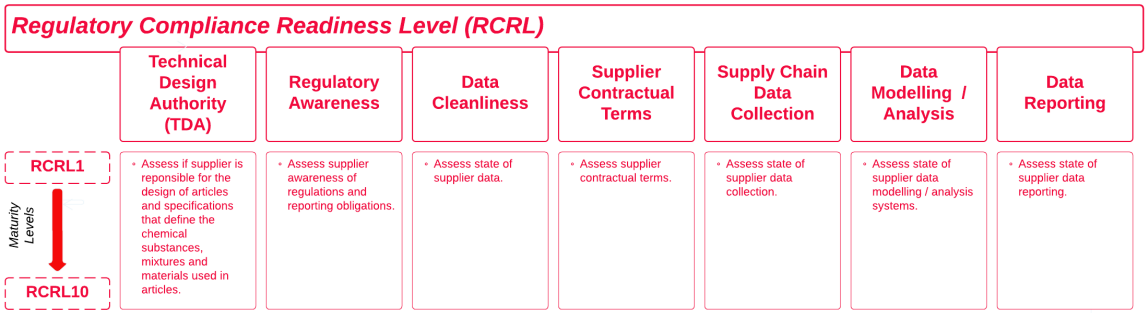


Figure 4-11: Regulatory Compliance Readiness Level (High-Level)

In the context of this research, stakeholder analysis has been utilised to identify stakeholders, the roles they perform and how they make act as potential sources of data.

4.6 Action Research and Simulation Research for Application and Contextual Investigation

To determine the most suitable implementation approach, the methodological requirements for the research strategy and research methods need to be:

1. Applicable to a typical AD organisation attempting to implement the conceptual framework with associated harmonised data load templates, data model and applications capable of being modified as required by the AD organisation.

2. Capable of enabling a typical AD organisation to perform a Gap analysis activity of current state activities versus to be contrasted against the desired state activities framed within the conceptual framework, to support AD organisational transformation challenges.
3. Provide a suggested road map of activities to be implemented as a robust and repeatable solution to multiple AD sector organisations.
4. Identify the data elements in the form of a data model which can be applied to multiple different types of existing sub-systems (PDMs, PLMs, ERPs, Data warehouses, custom databases, etc).
5. Provision data reporting that enables AD organisations to identify the potential impacts of chemical regulations.

The two research strategies adopted based on the methodological requirements above were noted as action research and simulation research, both of these approaches enable focus on a specific topic, enabling investigate analysis and awareness of real-world scenarios (Checkland and Holwell, 1998; Dresch et al., 2015). Action research entails the researcher working closely with participants exploring the phenomenon under investigation. In the context of this research study, action research was utilised via initial industry consultations and the Delphi studies focusing on specific topic areas, namely the data model, automation via blockchains and system output reporting. Action research was further utilised in terms of participants providing feedback for the harmonised data template design. Simulation research was favoured over case study research based on (1) the Delphi studies identifying a consensus on the core data model elements and data model, however, as additional as changes to the data model occurred during the creation of representative test data / simulation / new regulatory reporting requirements, the data model was re-validated with applicable stakeholders; (2) the researchers previous experiences of working within the AD sector enabled a sound understanding of existing methodologies in use for identification of chemical substances on internally defined and supply chain sourced articles; (3) representative test data creation was based on the identification of sample BOMs which typical form articles ingested within an aircraft; (4) software design, configuration management, software testing and release and testing of reporting data was using standardised IT system implementation approaches utilised by the author in previous roles implementing enterprise level IT systems within AD organisations. Simulation research as described in Chapter 7 was conducted via (1) generation of representative test data based on

a fictional AD organisation with real-world examples AD article descriptions, BOMs, specifications, etc; (2) harmonised data load templates populated with the representative test data and review status values for applicable business units; (3) data ingested from the harmonised data load templates into application(s) designed against the data model; (4) system output reporting highlighting potential business continuity risks; (5) risk assessment and mitigation actions being performed by applicable review boards.

4.7 Chapter Summary

Identification of data sources for AD articles, whether internally or externally defined is critical to enable the process for collecting the required substance related information to be ingested within the data model to enable potential business continuity risks posed by chemical regulations to be identified. The data sources and resultant data elements (different types of data) feed into the design of the data model defined within the Conceptual Framework. The outcome of this study is to develop a conceptual framework to support the identification of potential business risks posed by chemical regulations, and aid AD organisation decision-making process in terms of potential risk mitigation action(s). he implementation path for the conceptual framework encompasses:

1. *Roadmap*: definition of a high-level roadmap of activities for implementation.
2. *Data Model*: data elements capable of being implemented independently or across single / multiple existing systems.
3. *Internal Processes*: establishment of internal stakeholders to collect data via harmonised data load templates.
4. *Supply Chain Processes*: establishing external supply chain chemical reporting data collection processes which can then be transposed onto the harmonised data load templates.
5. *Identification of Business Continuity Risks*: system output reporting highlighting potential risks in terms of regulated chemical appearing on articles sold by the AD organisation.
6. *Risk Mitigation*: establishing internal review boards to perform risk analysis and mitigation actions

This chapter examined the conceptual framework design in terms of a systematic process flowing from the theoretical framework. The author has utilised the Theoretical Framework

to define initial state stakeholders, roles, and data, which are further explored in the Conceptual Framework as a data model running against a resultant application to ingest data, performing data analysis that results in the system output reporting driving risk identification and mitigation activities.

Chapter 5: Delphi Studies Validation Process and Results

5.1 Introduction

This chapter presents the Delphi studies undertaken as part of this research and applicable findings. The structure of this chapter is shown in Figure [5-1].

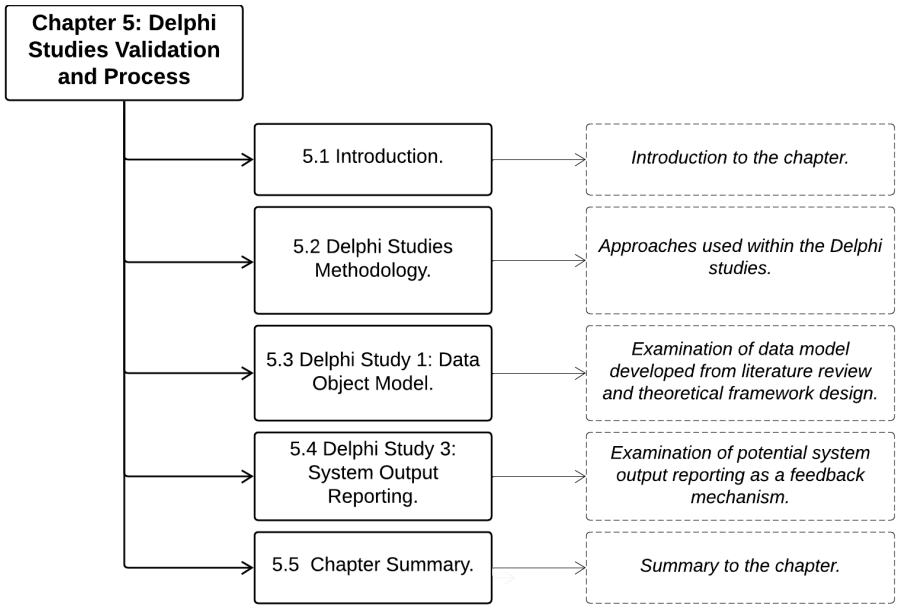


Figure 5-1: Chapter 5 Structure

5.2 Delphi Studies Methodology

5.2.1 Introduction

Delphi studies utilize group of experts to explore an issue over several rounds of surveying to arrive at an agreed outcome / consensus. The judgement from a group of experts is considered to be more valid than relying on the judgement from just a single expert (Williams and Webb, 1994; Phillips, 2000; Okoli and Pawlowski, 2004; Emmel, 2013).

5.2.2 Methodology

The methodology adopted in each Delphi study involved the use of online questionnaires being posted to an expert group of users (Okoli and Pawlowski, 2004; Chang, et al., 2010; Keeney, McKenna and Hasson, 2011). Each Delphi study started with an introduction to the concept being surveyed, followed by additional iterative rounds of surveying based on the responses from earlier rounds.

5.2.3 Criteria for Selection of Delphi Participants

Participants were identified via email based on the following criteria: (1) authors of existing research publications; (2) consultants who regularly publish online articles; (3) academia, lecturers in the related topic areas; (4) authors known AD sector regulatory specialists, and; (5) other participants who expressed an interest to participate in Delphi study through a series of LinkedIn posts (Takhar, 2018a; Takhar, 2018b; Takhar, 2018c; Takhar, 2019b). Participant types (1), (2), (3) and (4) follow a defined process on how experts may be included within a Delphi study (Okoli and Pawlowski, 2004; Emmel, 2013).

5.2.4 Delphi Study Design

For each of the Delphi studies conducted, the design of each Delphi study was designed to illicit both closed (directed) and open (illicit feedback) type question responses from participants, to enable both review and brainstorming of the applicable topic (Okoli and Pawlowski, 2004; Emmel, 2013). Three rounds of questioning took place within each Delphi study. Each round of the Delphi study built upon the responses of the earlier rounds (Ruschkowski et al., 2013; Emmel, 2013). Key assumptions prior to the commencement of each Delphi study were: (1) round 1: define basic concepts, ensure respondents understood the topic under review; (2) round 2: summarize the findings in round 2, develop concept further using the feedback comments from round 1; (3) summarize findings, refine concept, and re-validate any topics where consensus not reached in round. Each round of the Delphi study was presented as an online questionnaire, in which participants were invited via email to complete within an allocated time frame of at least 3 weeks duration, prior to the commencement of the next round. Individual participant responses were kept anonymously from other participants, to ensure the results did not influence other participants. The identity of each expert user was protected from the other members of the expert group, responses were identified where applicable as being respondent A, B, C, etc. Where applicable support was offered by email and webinars to aid respondent awareness.

5.3 Delphi Study 1: Data Model

5.3.1 Aim of Delphi Study

The aim of this Delphi study was to determine review and agree a consensus against the initial data model. The data model will form the basis for developing the framework to enable organisations to determine chemical substances they are using, against applicable chemical regulations, to determine areas of potential business risk(s).

5.3.2 Duration, Response Rates and Respondent Industry Sectors

Three rounds of Delphi surveys were conducted between September 2018 until December 2018. The location of the online surveys and response rates are shown in Table [5-1]. This Delphi study did not explicitly record respondent industry sectors in the questionnaire, the sectors were noted in a matrix used to identify potential respondents, the respondents were selected from aerospace, academia, blockchain, distributors, legal, medical devices, NGOs, plastic coating and polymer suppliers and software specialists.

Table 5-1: Survey Locations and Response Rates

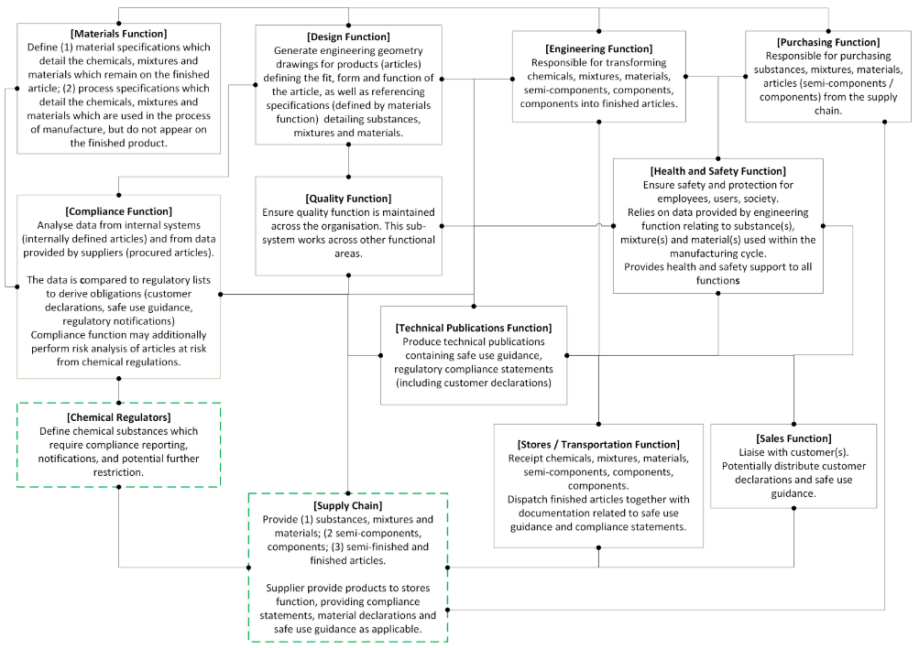
Round	Survey Link	Invited participants	Completed responses	Incomplete responses
1	Delphi study 1 – Round 1	45	21 (46.66%)	1 (2.22%)
2	Delphi study 1 – Round 2	21	17 (80.95%)	2 (9.52%)
3	Delphi study 1 – Round 3	17	16 (94.12%)	1 (5.88%)

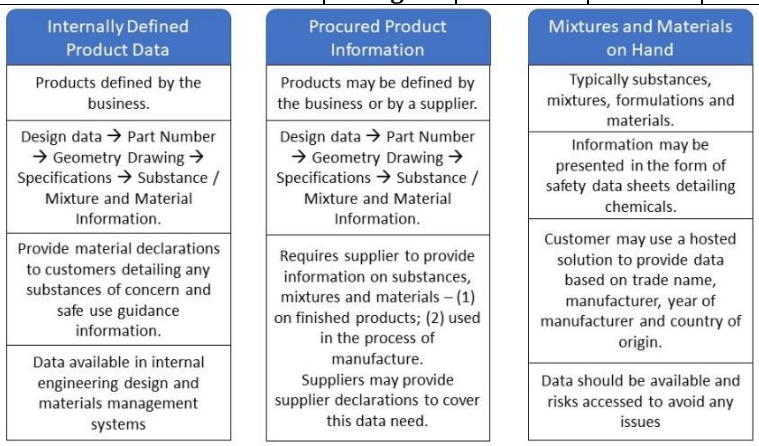
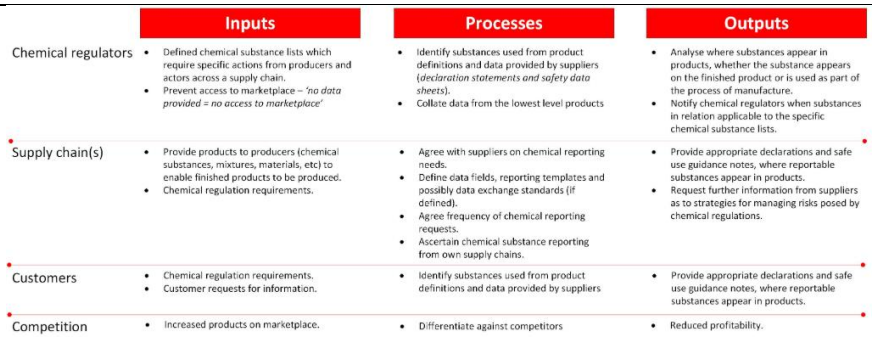
5.3.3 Delphi Study 1: Round 1 Findings

Table [5-2] details a summary of the findings.

Table 5-2: Delphi Study 1: Round 1 Findings

Section	Answer	1 Strongly Disagree	2 Disagree	3 Agree	4 Strongly Agree
The role of manufacturers	Products may be manufactured internally or sourced from a supply chain	0.0% (0)	14.3% (3)	47.6% (10)	38.1% (8)
	Objective of manufacturers is to produce products for maximum profit.	4.8% (1)	23.8% (5)	42.9% (9)	28.6% (6)
The role of chemical regulations.	Chemical regulations provide lists of substances where specific obligations are required.	0.0% (0)	28.6% (6)	47.6% (10)	23.8% (5)
	Objective of chemical regulations is to control hazardous chemical substances.	4.8% (1)	23.8% (5)	52.4% (11)	19.0% (4)
Basic article (product) definitions.	Process specifications reference the chemical substances, mixtures and materials which are used in the process of manufacture only, not appearing on the final product.	4.8% (1)	9.5% (2)	57.1% (12)	28.6% (6)
	Material specifications reference the chemical substances, mixtures and materials which are present in the finished product.	4.8% (1)	9.5% (2)	66.7% (14)	19.0% (4)
	Geometry drawings define the basic shape, form and function of a given product.	9.5% (2)	14.3% (3)	61.9% (13)	14.3% (3)

Section	Answer	1 Strongly Disagree	2 Disagree	3 Agree	4 Strongly Agree
Stakeholders See Figure [5-2].	 ***Figure 5-2: Stakeholder system context diagram***				
	The stakeholders depicted in the figure are a fair representation of those within your organisation.	9.5% (2)	14.3% (3)	61.9% (13)	14.3% (3)
	The stakeholders depicted in the figure enables you to identify all the data needed to meet your chemical substance reporting needs.	9.5% (2)	14.3% (3)	66.7% (14)	9.5% (2)
	Respondent feedback comments: (1) Respondent A: Supply chain MUST interact with Compliance directly to obtain chemical data. Health and Safety and Compliance must interact to determine the suitability of materials and requirements for safe handling. You have no manufacturing function. Engineering in the chemical process industry would develop the manufacturing process and not the formulation. Transportation and stores must include purchased materials (raw materials, processing aids) as well as finished goods. Author comments: Update to reflect missing requirements. (2) Respondent B: *I would expect to see a Supply-Chain function within most large complex organisations these days*. Author comments: Accept comment, but not make major changes as the activities of a specific supply chain function can be distributed across other functional areas beyond purchasing function, such as supplier audits and product quality checks via quality and stores function.				

Section	Answer	1 Strongly Disagree	2 Disagree	3 Agree	4 Strongly Agree
Sources of information see Figure [5-3].	 ***Figure 5-3: Potential sources of data***				
	Internal product definitions are as described.	4.8% (1)	9.5% (2)	66.7% (14)	19.0% (4)
	Procured product information are as described.	0.0% (0)	14.3% (3)	76.2% (16)	9.5% (2)
	Chemical substances, mixtures and materials on hand are as described.	9.5% (2)	4.8% (1)	61.9% (13)	23.8% (5)
	Respondent feedback comments: (1) Respondent A: *important is up-dating of data and communication. Internally is done*. From suppliers not always. Author comment – accept without making any design changes. (2) Respondent C: SDS's are designed for communication of hazard substances in the workplace. They should NOT be misused for chemical substance reporting. Under GHS, only hazardous substances present above reporting thresholds must be declared. A full material disclosure is required to determine composition information. For the chemical process industry, a separate regulatory data system is employed. While it may be a module within an ERP system, it is typically NOT integrated fully into the ERP system. For IP reasons, much of the data on substances may need to be kept in a separate system with access limited to regulatory personnel. Author comments: Agree with the statement that data can be found in numerous sub-systems. However, must state SDS documents do have a regulatory compliance section which do make applicable regulatory statements. The logic is to look for the most valid / accurate sources whether they are (1) from product definitions such as material / process specifications; (2) supplier material declarations, or from (3) SDS type documents which state hazardous substance information, or from (4) international databases such as the ECHA Poison Centre Database when made available in 2021.				
Actors / factors, inputs, processes, and outputs, see Figure [5-4].	 ***Figure 5-4: Actors, Inputs, Processes, Outputs***				
	Do these actors, inputs, processes, and outputs represent the main external actors for a chemical reporting system?	Yes, 47.62% (10), I am not an expert in this area, 28.57% (6), No, 23.81%, (5).			

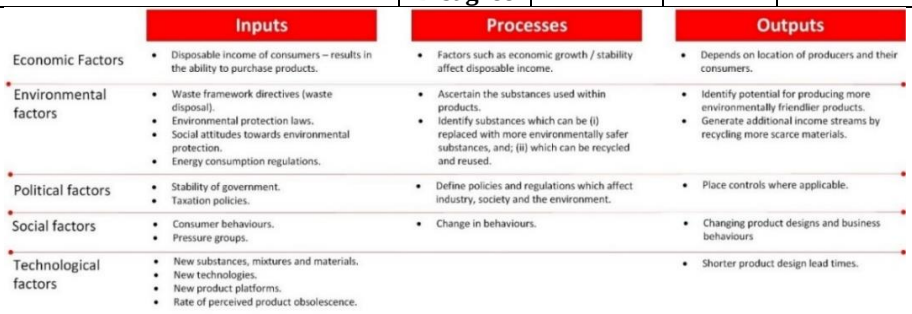
<table>
<tr><th>Section</th><th>Answer</th><th>1 Strongly Disagree</th><th>2 Disagree</th><th>3 Agree</th><th>4 Strongly Agree</th></tr>
<tr><td rowspan="3">External factors, see Figure [5-5].</td><td colspan="4"> 

Figure 5-5: External Factors, Inputs, Processes, Outputs</td></tr>
<tr><td colspan="2">Do these external factors, inputs, processes, and outputs represent the main factors for a chemical reporting system?</td><td colspan="3">Yes, 66.67% (14),
I am not an expert in this area, 19.05% (4),
No, 14.29%, (3).</td></tr>
<tr><td colspan="5">Respondent feedback comments:
(1) Respondent A: Taxation policies must include trade barriers (regulatory, tariff, VAT, etc.) in addition to corporate and personal income tax. Economic factors need to include basic materials costs (oil, electricity, minerals, etc.) for the manufacturing sector, along with labor costs. These impact manufacturing location, impacting materials available for the process from an economic and regulatory perspective. Author comments: Agree with the statement and update design accordingly.</td></tr>
</table>

A closing question was presented using a Likert scale with a range of 1 being not important through to 10 extremely important, the respondents asked to rank factors in terms of importance to a chemical reporting system, the top 5 responses were as follows: (1) lack of common data formats, standards, prevent adoption within industry sector(s) rated at 7 (35%); (2) increased customer requests for reporting rated at 7 (30%); (3) strong leadership is needed across the organisation to ensure engagement between internal and external stakeholders rated at 6 (28.6%); (4) internal product definitions need to be cleaned up and accurate rated at 6 (28.6%); (5) establish supplier agreements to perform reporting rated at 6 (28.6%). The responses to this question suggested respondent alignment to needing standardized formats; increased customer requests; strong leadership support needed to aid any implementation; data cleansing activities and supply chain engagement needed to support a chemical reporting system

5.3.4 Delphi Study 1: Round 2 Findings

This round of the Delphi study built upon on the first round Delphi study. Respondents were presented with potential tables in terms of capturing data for different functional areas within an organisation, the respondents were asked to confirm agreement to each proposed table meeting the basic needs for a chemical reporting system. The underlying logic was to validate the existing data model design and identify any missing gaps. At this stage of the

Delphi study, it appeared respondents were in general agreement as to the basic tables being proposed for the data model.

5.3.5 Delphi Study 1: Round 3 Findings

Respondents were presented with a use case diagram for a chemical substance reporting system as shown in Figure [5-6].

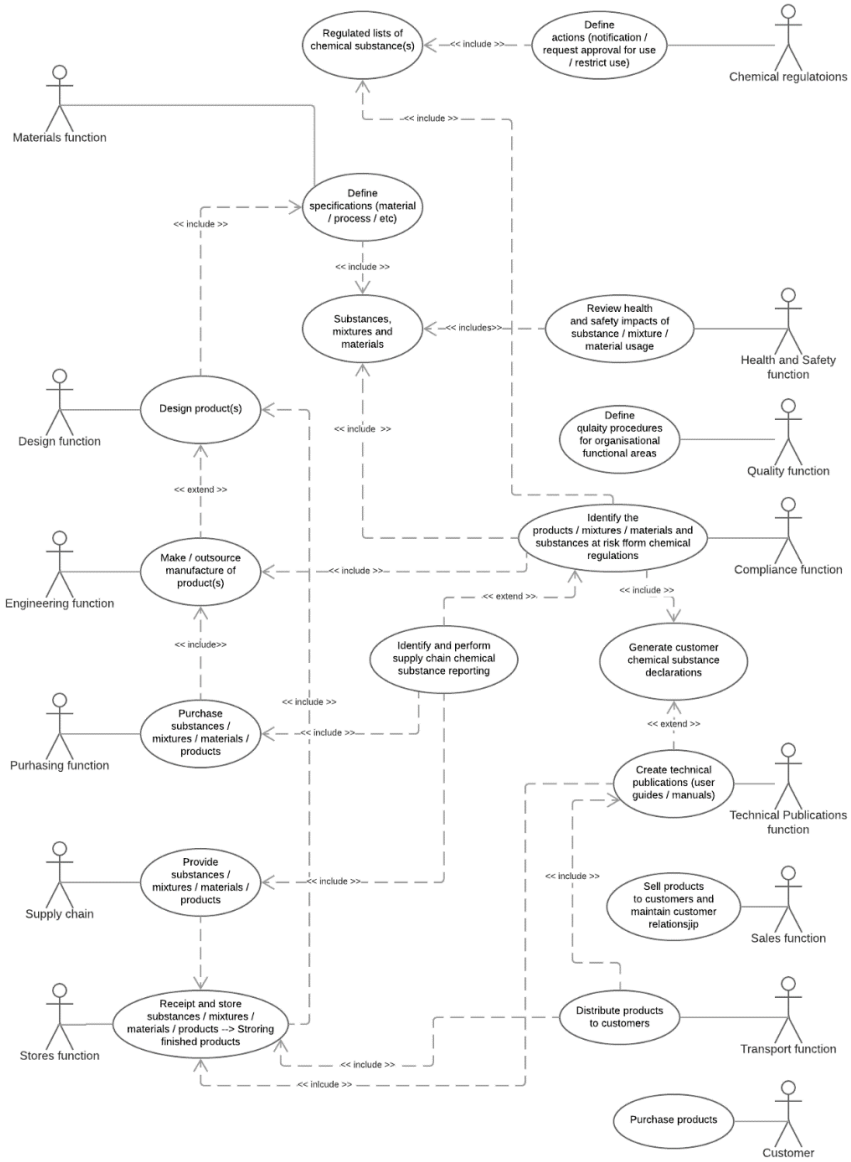


Figure 5-6: Use Case Diagram for a Checmical Substance Reporting System

The results were as follows: (1) agreed (62.5%); (2) neither agreed nor disagreed (31.3%); (3) did not agree that (6.2%) that the use case diagram in Figure [5-6] represented a chemical reporting system. Respondents were asked to review Figure [5-7] together with a definition. The results were as follows: (1) agreed (68.8%); (2) neither agreed nor disagreed (25%); (3) did not agree that (6.2%).

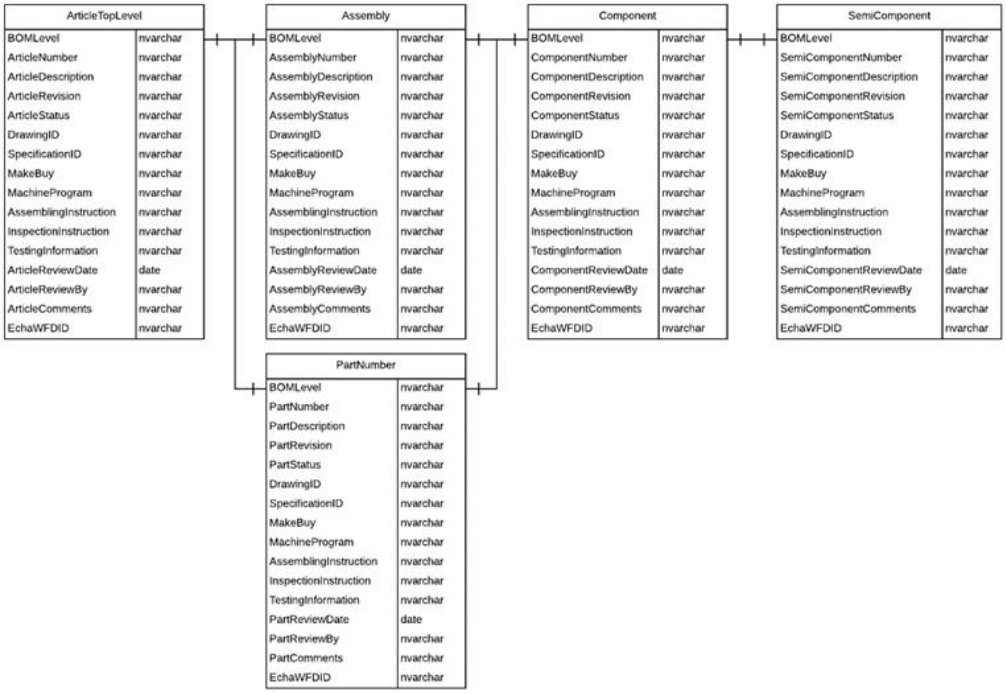


Figure 5-7: Proposed Data Model to Capture Article Structures

Respondents were asked to review Figure [5-8] together with a definition. Respondents were asked to state if they agreed that this met the needs for capturing product structured related information. The results were as follows: (1) agreed (72.5%); (2) neither agreed nor disagreed (18.8%); (3) did not agree that (9.7%).

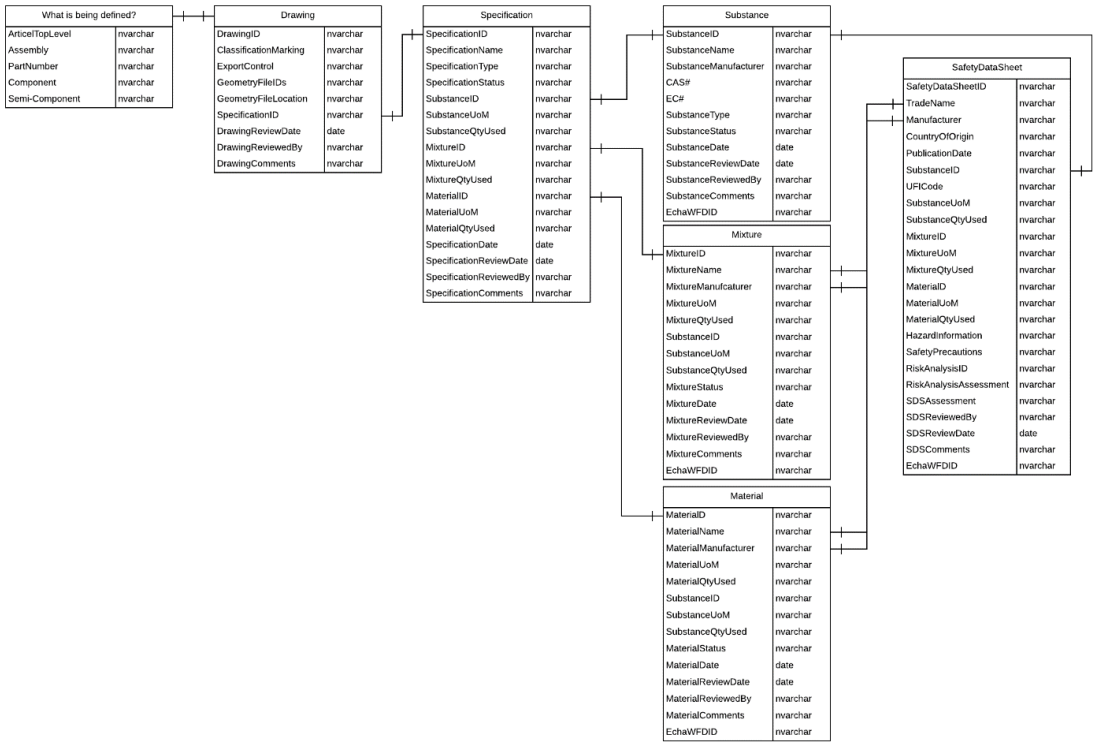


Figure 5-8: Proposed Data Model to Collect Article Substance Information

Respondents were asked to review Figure [5-9] together with a definition. Respondents were asked to state if they agreed that this met the needs for capturing product structured related information. The results were as follows: (1) agreed (68.8%); (2) neither agreed nor disagreed (22.2%); (3) did not agree that (9%).

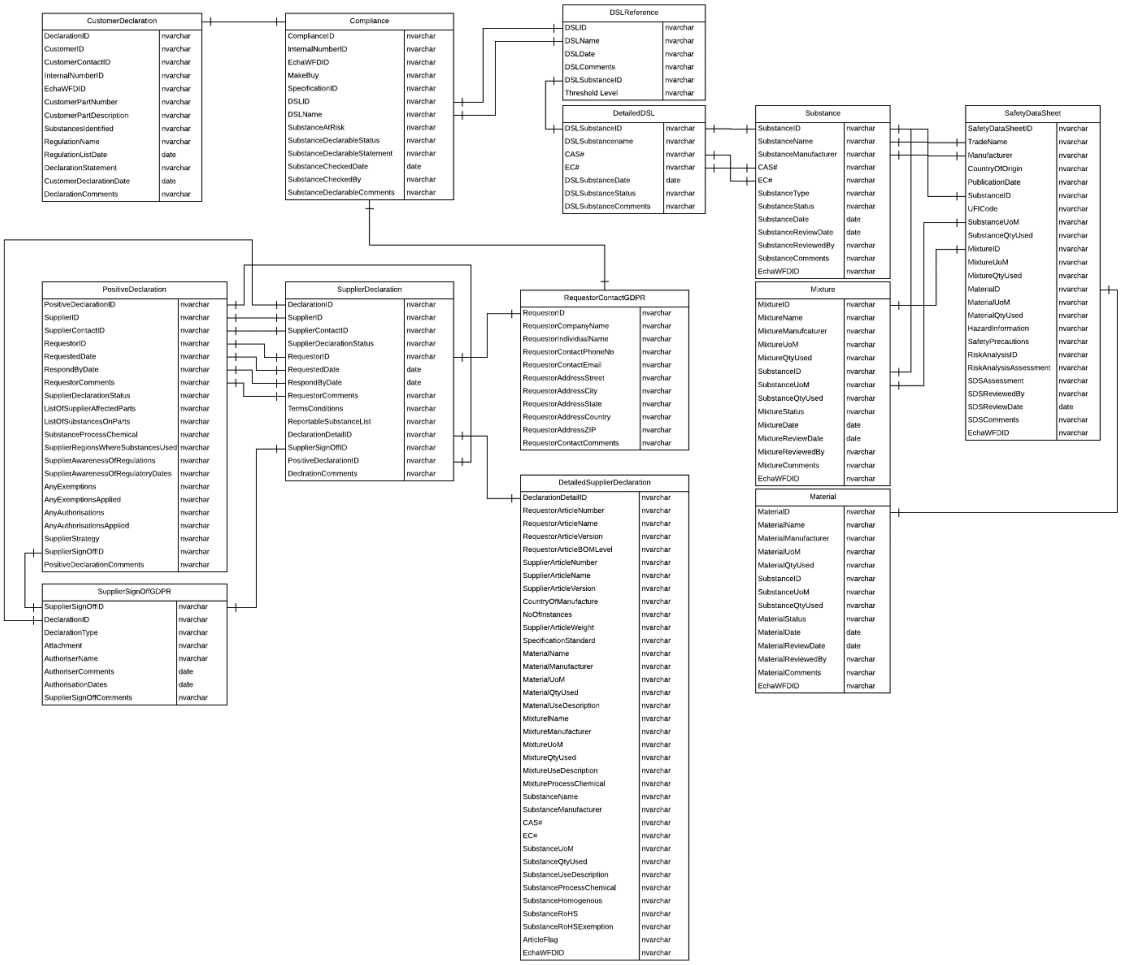


Figure 5-9: Required Data Tables to Support Chemical Substance Reporting System

Respondent feedback comments: (1) Respondent A: *Customer's often have restrictions on the use of substances beyond those identified by regulations. An additional input should be included for this function. How do you account for global/regional supply chains? For example, US military procurement is generally not impacted by EU SVHCs, though it can be, and it is often impacted by US hazardous air pollutant regulations. Similarly, some dual use materials are not available in China due to the need for approval by non-standard Ministry's (such as agriculture). I think this should be called out by a separate data node as environmental regulations*. Author comments: Agree with the statement and extend DSLs to include more regulatory requirements.

(2) Respondent C: *Chemical inventory status by jurisdiction, as this may be different, particularly for mixtures. This can be stored at the substance/mixture level and is needed until everything that is in a part is an article (e.g. kits may be a mixture of articles and chemicals and must comply with applicable chemical regulations).* Author comment: accept comments and adjust final design to reflect comments.

Respondents were asked to review Figure [5-10] together with a definition. Respondents were asked to state if they agreed that this met the needs for capturing product structured related information. The results were as follows: (1) agreed (68.5%); (2) neither agreed nor disagreed (25%); (3) did not agree that (6.5%).

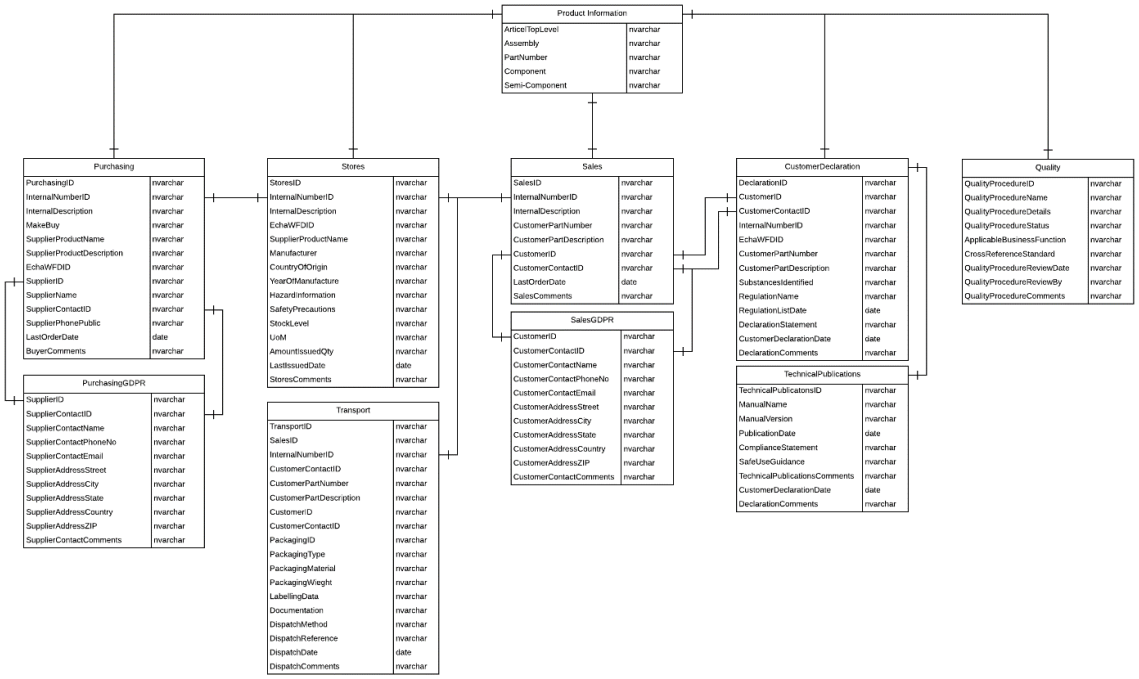


Figure 5-10: Data Tables to Support Other Users

The closing question in this round asked respondents to state if different elements presented should be included in a data model for chemical substance reporting, the elements that the respondents felt should be include, the top 5 selected answers were as follows: (1) identify a part structure (single article) in terms of a definition such as a drawing / specification (68.8%); (2) identify regulated substances found on internally defined products (68.8%); (3) enable data to be imported from multiple sources (62.5%); (4) create a chemical substance inventory for procured chemicals, mixtures and materials (62.5%); (5) enable querying to assess the impact of any substance being regulated (62.5%).

5.4 Delphi Study 2: Conceptual Blockchain Model

The outcomes of this Delphi study did not impact the final data model design. The key aim of this Delphi study was to examine the potential to automate: (1) supply chain data reporting requests and (2) supplier data collection and data reporting. Appendix [17] contains the detailed reporting information for this Delphi study.

5.5 Delphi study 3: System Output Reporting as a Feedback Mechanism

5.5.1 Introduction

The primary purpose of this Delphi study was to example the ways in which the needs of chemical regulations, CSR and the circular economy could potentially feedback into decision making systems such as product stewardship.

5.5.2 Duration, response rates and respondent industry sectors

Three rounds of Delphi surveys were conducted between March 2019 until August 2019. The location of the online surveys and response rates are shown in Table [5-3].

Table 5-3: Delphi study 3: survey links and response rates

Round	Survey Link	Invited participants	Completed responses	Incomplete responses
1	Delphi Study 3 – Round 1	73	38 (52.05%)	4 (2.92%)
2	Delphi Study 3 – Round 2	38	29 (76.32%)	
3	Delphi Study 3 – Round 3	29	20 (68.96%)	5 (17.24 %)

The industry sectors respondents worked within were: (1) producer of articles (31.58%); (2) other: recycler, NGO, consultant (26.32%); (3) Original Equipment Manufacturer (OEM) - the article designer / technical authority (21.05%); (4) importer of articles (18.42%); (5) educational establishment (18.42%); (6) retailer / distributor of articles (10.53%); (7) consumer of articles (7.89%). The age groups respondents belonged to were: (1) 36-45 (39.47%); (2) 46-55 (23.68%); (3) 56-65 (18.42%); (4) 26-35 (10.53%); (5) unwilling to disclose (9.80%); (6) over 65 (7.89%).

5.5.3 Delphi study 3: Round 1 Findings

This round of the Delphi study aimed to provide respondents with some conceptual foundations relating to product stewardship, chemical regulation related reporting, sustainability, circular economy, and corporate social responsibility. Figure [5-11] shows a summary from the short form questions presented in this round of the Delphi study.

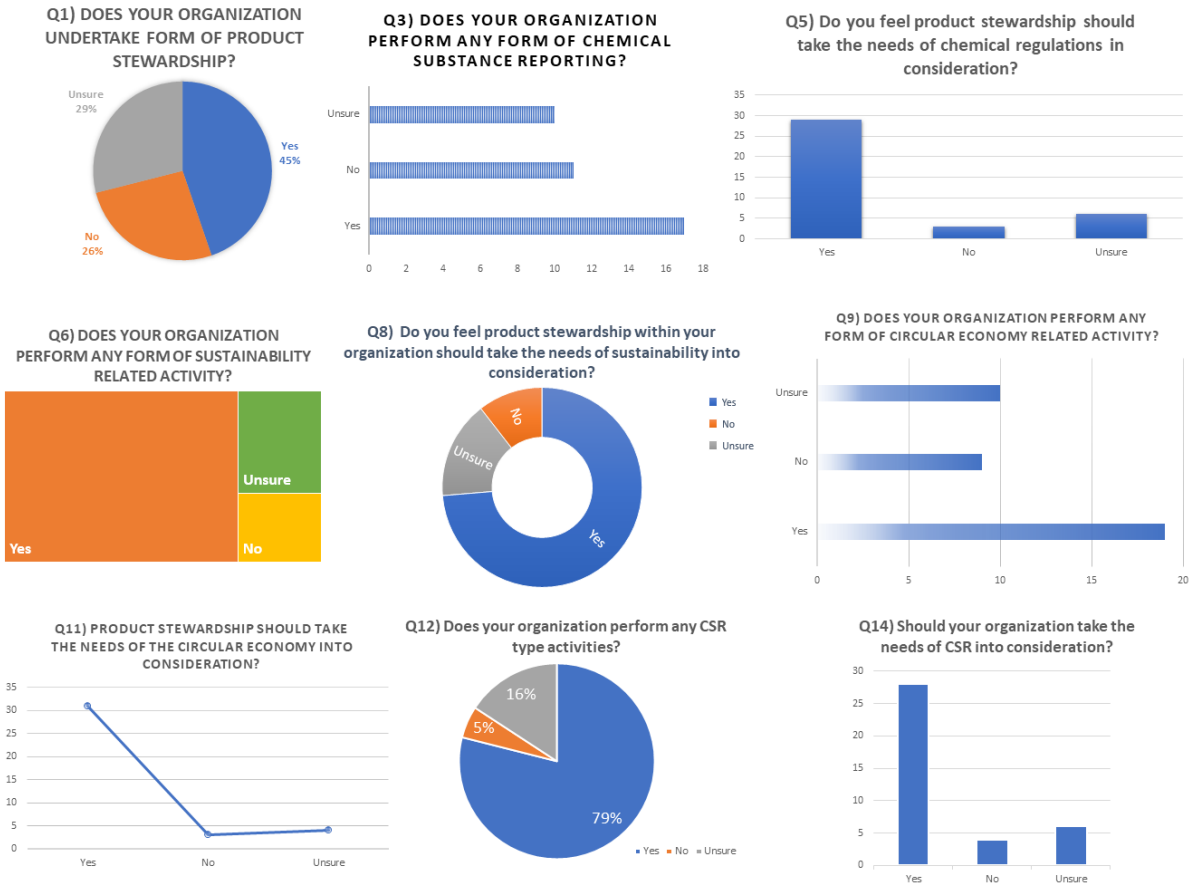


Figure 5-11: Delphi study 3: Round 1 summary of short form questions

Table [5-4] details a summary of the multiple answer questions with the top 5 answers identified by respondents.

Table 5-4: Delphi study 2: Round 1 long form question summary

#	Question logic	Top 5 Answers
2.	Identify from a list of product stewardship examples, which ones were in use within their organisation.	• Senior management buy-in for product stewardship, yes (55.3%); • Product stewardship commitment communicated to all employees, yes (44.7%); • Use of sustainable practices [design, manufacture, natural resource consumption], yes (44.7%); • Product stewardship is integrated into senior management decision making processes, unsure (42.1%); • Supply chain data sharing, understand any risks and hazards across a supply chain, yes (42.1%).
4.	Identify from a list of chemical reporting examples, the ones were in use within their organisation.	• Provide statements in user manuals, unsure (44.7%); • Requesting chemical substance reporting information from the supply chain, yes (42.1%); • Responding to customer requests for chemical substance reporting information, no (42.1%); • Assessing Material Safety Data Sheets (MSDS) or Safety Data Sheets (SDS) when substances and mixtures arrive on site, yes (39.5%); • Chemical regulation formatted statements [REACH, RoHS, Prop 65, WEEE, etc.], yes (39.5%).

#	Question logic	Top 5 Answers
7.	Identify from a list of sustainability examples, which ones were in use within a respondent organisation.	• Develop internal programs to conserve energy use [use of LED / fluorescent lightbulbs], yes (65.8%); • Use of renewable energy [solar / wind power], yes (57.9%); • Use of in-house recycling programs, yes (52.6%); • Use of environmentally friendly chemicals and products from the supply chain, yes (44.7%); • Reducing the amount of pollution, yes (44.7%).
10.	Respondents to identify from a list of circular economy examples, which ones were in use within their organisation.	• using take-back schemes where manufacturers take back products and provide consumers with a monetary return. For example, soft drinks delivered in a glass bottle where the selling price includes a deposit fee, which when a consumer has consumed the drink, is returned to the consumer upon return of the glass bottle, which is then cleaned and reused, no (55.3%); • consumers are encouraged to rent products as opposed to outright purchase. The products are returned to the manufacturer upon assumed end-of-life from a consumer, where the manufacturer will then perform repair, refurbishment, recycling activities, no (52.6%); • reduce the amounts of consumer demand and use of scarce materials by a manufacturer, yes (50%); • repurpose products for new uses, no (47.4%); • remanufacture products where new parts may be added to a product, no (44.7%).
13.	Identify policy commitments in relation to CSR conducted within their organisations.	• Is this policy publicly available [web site / printed materials]? yes (76.3%); • Has this policy been communicated to all employees? yes (73.7%); • Has this policy been approved by senior management? yes (68.4%); • Has this policy been communicated to tier 1 suppliers? no (39.5%); • Are there any procedures in place to ensure compliance to the policy? no (42.1%).
15.	Select from list of factors, those could potentially influence the way an organisation performs any type of reporting.	• employers, yes (71.1%); • employees, yes (71.1%); • shareholders, yes (60.5%); • business partners, yes (50%); • regulators, yes (44.7%).

Participant feedback comments have not been included in the responses for this round as they were general statements where two respondents kept stating not applicable to each answer.

5.5.4 Delphi study 3: Round 2 Findings

The second round of the Delphi study focused product lifecycle and potential framework questions. Figure [5-12] shows a summary from the short form questions presented in this round of the Delphi study.

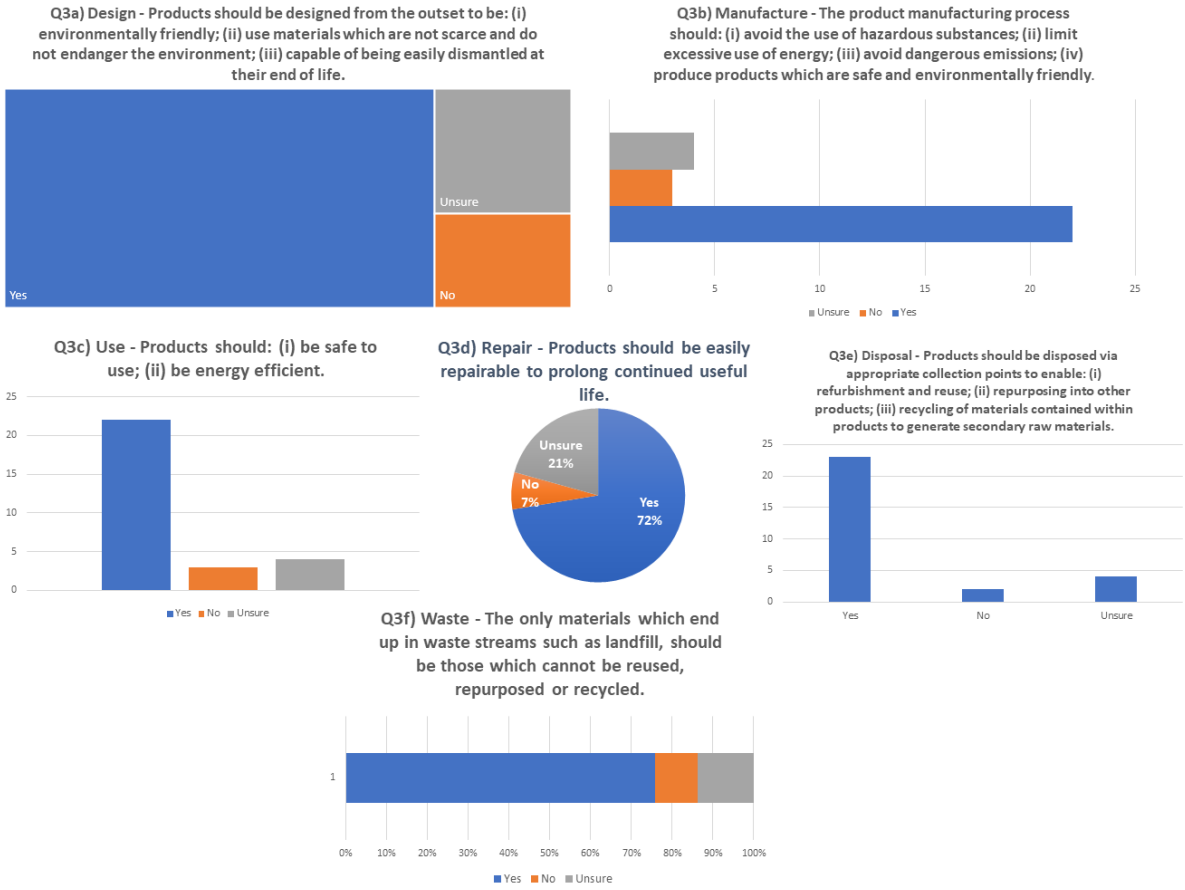


Figure 5-12: Delphi study 3: Round 2 summary of short form questions

Respondent feedback comments: (1) Respondent J: *Some products, such as semiconductors or specialty alloys, may require use of scarce materials. If used in small quantities and responsibly sourced, this could be acceptable. Some products may not be appropriately dismantled. Consider, for example, down-the-drain soaps and detergents. Not all products are appropriately repaired or disposed of through reuse, repurposing, or recycling. Again, consider down-the-drain products or food products*. Author comment: accept comments and adjust final design to reflect comments.

Table [5-7] details a summary of single question where respondents were asked to select the most applicable questions to use in a framework, the top 10 response rates are shown.

Respondent feedback comments: (1) Respondent L: *How much energy is needed to manufacture a product?"" note that most factories produce multiple products. The question should ask how much energy is used by the company in the aggregate, not on a product basis*. Author comment: accept comments and adjust final design to reflect comments.

Respondent feedback comments: (2) Respondent Q: *What are the biggest barriers your institution faces in integrating these concepts into design and supply chain activities?* Author comment: accept comments and adjust final design to reflect comments.

Table 5-5: Delphi study 2: Round 2 potential framework questions

#	Framework Question	Response Percent	Response Total
5.	Are any renewable energy sources utilized?	72.41%	21
6.	How much waste is generated as part of the manufacturing cycle?	68.97%	20
18.	Are any product collection schemes used when a product reaches the end of its useful life? - if there are any, how are they implemented and managed	62.07%	18
3.	What are the materials required to manufacture a product?	58.62%	17
4.	How much energy is needed to manufacture a product?	58.62%	17
7.	How is the waste generated as part of the manufacturing cycle handled?	58.62%	17
10.	Are any previously used products recycled? - how are materials prioritized for recycling activities?	58.62%	17
16.	Have you taken any steps to integrate your supply chain towards sustainability and the circular economy?	58.62%	17
17.	Do you perform any supply chain monitoring activities with regards to compliance with (i) chemical regulations; (ii) sustainability, (iii) the circular economy, and; (iv) corporate social reporting?	58.62%	17
12.	Have you identified the economic, social, and environmental impacts of your products?	51.72%	15

5.5.5 Delphi study 3: Round 3 Findings

This final round of the Delphi study reviewed concepts from earlier rounds of the study. Table [5-8] presents a summary of the top 3 responses to a series of questions where respondents were able to select multiple answers.

Table 5-6: Delphi study 2: Round 3 summary

Section	Answer	Agree	Disagree	Unsure	N/A
Product Stewardship.	Product stewardship impacts a wide range of business activities.	85.0% (17)	5.0% (1)	10.0% (2)	0.0% (0)
	Product stewardship examines the environmental, health and safety impacts of a product across its entire lifespan.	75.0% (15)	20.0% (4)	5.0% (1)	0.0% (0)
Product Design.	When a product is first designed it shall be reviewed by Product Stewardship.	75.0% (15)	10.0% (2)	10.0% (2)	5.0% (1)
	As product design changes occur, there should be some form of gated review by Product Stewardship.	70.0% (14)	15.0% (3)	10.0% (2)	5.0% (1)
	Products shall be designed to be energy efficient, to be reviewed by Product Stewardship.	65.0% (13)	10.0% (2)	20.0% (4)	5.0% (1)
Procurement.	Internal energy consumption rates shall be reviewed by Product Stewardship.	70.0% (14)	10.0% (2)	15.0% (3)	5.0% (1)
	Purchasing criteria for products labelled as being environmentally friendly shall be reviewed by Product Stewardship.	70.0% (14)	10.0% (2)	15.0% (3)	5.0% (1)
	A decision will be made to manufacture products internally or outsource production	55.0% (11)	20.0% (4)	20.0% (4)	5.0% (1)

Section	Answer	Agree	Disagree	Unsure	N/A
	to the supply chain, data shall be reviewed by Product Stewardship.				
Product Manufacture.	Existing manufacturing processes shall be reviewed by Product Stewardship.	65.0% (13)	10.0% (2)	20.0% (4)	5.0% (1)
	Substances, mixtures, and materials contained within finished products manufactured internally are identifiable and reviewed regularly by Product Stewardship.	60.0% (12)	15.0% (3)	20.0% (4)	5.0% (1)
	Substances, mixtures, and materials used within the manufacturing processes are identifiable and reviewed regularly by Product Stewardship.	60.0% (12)	20.0% (4)	15.0% (3)	5.0% (1)
Production Release Stage.	Ensure any product risks to the environment are identified as part of the design and manufacture cycles and reviewed by Product Stewardship.	75.0% (15)	10.0% (2)	10.0% (2)	5.0% (1)
	Ensure products have appropriate safe use guidance and it is reviewed by Product Stewardship.	70.0% (14)	10.0% (2)	15.0% (3)	5.0% (1)
	Ensure any product risks to human health are identified as part of the design and manufacture cycles and reviewed by Product Stewardship.	60.0% (12)	20.0% (4)	15.0% (3)	5.0% (1)
Consumer Use.	Procedures should be defined in relation to proper use of products and reviewed by Product Stewardship	65.0% (13)	10.0% (2)	20.0% (4)	5.0% (1)
	Clear instructions for consumers on in relation to product disposal are reviewed by Product Stewardship.	65.0% (13)	10.0% (2)	20.0% (4)	5.0% (1)
	Clear instructions for consumers to request product repairs are reviewed by Product Stewardship.	60.0% (12)	10.0% (2)	25.0% (5)	5.0% (1)
Supply Chain Management.	Supplier shall be encouraged to provide data on how much waste is created to manufacture a product, this information may be reviewed by Product Stewardship.	65.0% (13)	15.0% (3)	10.0% (2)	10.0% (2)
	For new suppliers, any supplier assessment shall include a review by Product Stewardship.	65.0% (13)	15.0% (3)	10.0% (2)	10.0% (2)
	Suppliers should demonstrate a commitment to sustainable supply chains (certification against ISO 14001 / ISO 9001 / ISO 20400 / OHSAS 18001 / SA8000 / other) this should be reviewed by Procurement and Product Stewardship.	65.0% (13)	15.0% (3)	15.0% (3)	5.0% (1)
Social Impacts.	Internal procedures should be defined in relation to human rights and reviewed by Product Stewardship.	55.0% (11)	15.0% (3)	25.0% (5)	5.0% (1)
	Internal employee working conditions should be reviewed by Product Stewardship.	55.0% (11)	15.0% (3)	25.0% (5)	5.0% (1)
	Reviews of any social improvement projects to aid local communities should be undertaken by Product Stewardship.	50.0% (10)	20.0% (4)	25.0% (5)	5.0% (1)
Towards the Circular Economy.	Where third party schemes are used to manage the collection, recycling, and disposal of EOL products, regular	65.0% (13)	15.0% (3)	15.0% (3)	5.0% (1)

Section	Answer	Agree	Disagree	Unsure	N/A
	performance reviews shall be conducted by Product Stewardship.				
	Where feasible, using data from waste stream operators, Product Stewardship may analyse the amount of residual non-recyclable waste which ends up in landfill waste sites. With the data feeding back into product design cycles to enable future reductions.	65.0% (13)	15.0% (3)	15.0% (3)	5.0% (1)
	Where procedures define the collection of End-of-Life (EOL) products from collection points or directly from consumers they should be reviewed by Product Stewardship.	55.0% (11)	30.0% (6)	10.0% (2)	5.0% (1)

Respondent feedback comments: (1) Respondent J in terms of product stewardship: *Too often industries take a narrow view of product stewardship. For example, companies making chemicals are very good at stewarding the chemicals from factory loading dock, through the factory to the transportation network to the next factory gate. However true stewardship needs to go further. True stewardship would look at consumer product use of chemicals, packaging, and energy to use the product (in the cases of laundry liquid and shampoo, for example*). Author comment: accept comments and adjust final design to reflect comments.

Respondent feedback comments: (2) Respondent L in terms of product stewardship: *By product one needs to include its packaging, logistics support and any take back of material involved. A question arises as to whether stewardship standards or certification are required. In my view they are mandatory, and fines allotted if not followed. as prescribed.* Author comment: accept comments and adjust final design to reflect comments.

Respondent feedback comments: (3) Respondent M in terms of product stewardship: *How much energy is needed to manufacture a product?"" note that most factories produce multiple products. The question should ask how much energy is used by the company in the aggregate, not on a product basis*. Author comment: accept comments and adjust final design to reflect comments.

Respondent feedback comments: (4) Respondent N in terms of product stewardship: *I agree products should be designed using materials which are not scarce; easily dismantled; non-hazardous; reusable; biodegradable; or energy efficient, and that product designs need to be reviewed appropriately, but such role may transcend that of Product Stewardship*

within an organisation. Author comment: accept comments and adjust final design to reflect comments.

5.6 Chapter Summary

This chapter described the Delphi studies undertaken as part of this research, which focused on investigating specific elements of the conceptual framework as shown in Figure [5-1] being data modelling, data collection and system reporting. The Delphi studies were reviewed and assessed by applicable expert panels consisting of academia, regulatory experts, software developers, a cross section of AD supply chain actors and experts from additional industrial sectors. This has enabled the detailed evaluation to be undertaken regarding the data modelling, data collection and system reporting.

5.6.1 Delphi study 1

The first Delphi study focused on data modelling and the development of a data model from the initially developed model shown in Takhar and Liyanage 2018a. This Delphi study was complex in terms of presenting the expert panel with the correct level of information to enable a balanced evaluation to be undertaken against the need to report against chemical regulations and analysing where potential sources of data could be identified to meet the reporting needs. The aggregation of feedback comments from participants then enhanced the development of the proposed data model. The data model was updated during July 2019, however evolving regulatory reporting requirements resulted on aspects of the design to be paused. Through author participation the in IT expert user groups for the ECHA SCIP database for the EU WFD 2018/851 (EC, 2018b), and the UK REACH-IT system design which is the UK solution for industry chemical substance reporting following Brexit, it became clear that those two systems were going to negatively impact the data model design. Changes have been applied to the data model shown in the detailed in the detailed design section, it is anticipated that additional changes may need to be applied to the data model to facilitate any additional reporting requirements needed by the AD to support the ECHA SCIP database and the UK REACH-IT system implementations during Q4, 2020.

5.6.2 Delphi study 3

The intention of this Delphi study was to validate a common set of data elements needed to establish a chemical reporting system. Additionally, the potential to re-align chemical substance reporting, sustainability and circular economy initiatives feeding back into

internal decision support systems such as product stewardship was examined. The resultant data model was supposed to form the basis for the framework, which would enable organisations to identify the risks of regulated hazardous substances within internally defined products and externally sourced products. Feedback comments from this Delphi study have been reviewed and changes are being applied to how the data model will function in terms of collecting data, analysing data and then perform output reporting. The findings from this Delphi study have been presented as a journal paper Takhar and Liyanage 2020c.

5.6.3 Lessons learnt

The main lessons learnt during the Delphi studies was: (1) connecting with each respondent pre and post each round of study undertaken; (2) supporting respondents with further clarification of the questions posed; (3) making the error during Delphi study 1, in not collecting respondent age groups and industry sector background information.

Chapter 6: Detailed Framework Design

6.1 Introduction

This chapter presents the detailed framework design. The structure of this chapter is shown in Figure [6-1].

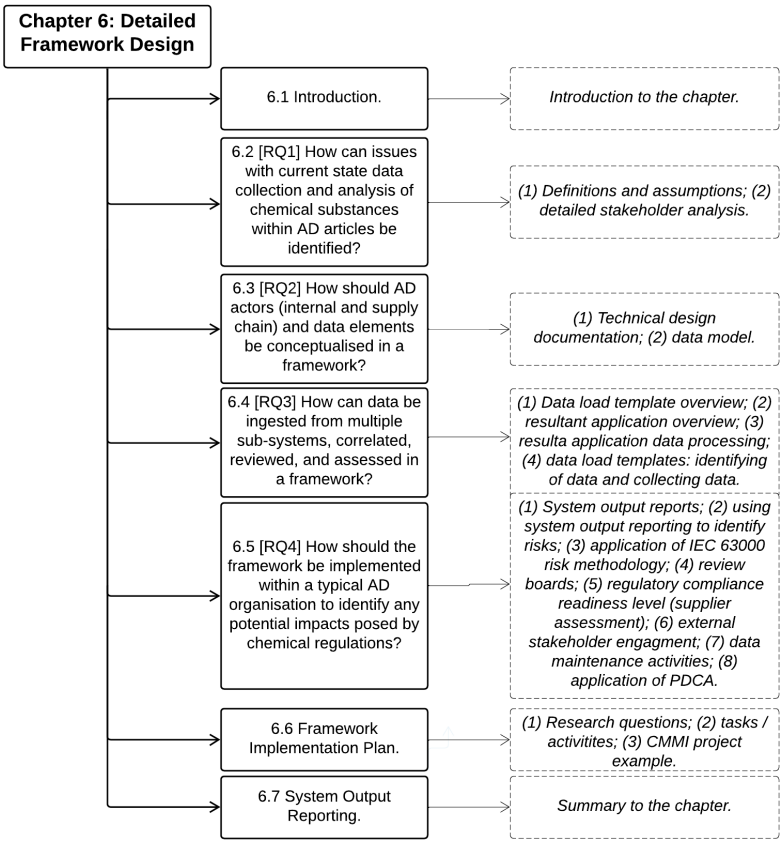


Figure 6-1: Detailed Framework Design Structure

The following sub-sections have been organised in the context of the four research questions set out in chapter 1.

6.2 [RQ1] How can issues with current state data collection and analysis of chemical substances within AD articles be identified?

This question addresses the initial PLAN and DEFINE phase activities. The activities are identified as: review definitions and assumptions as shown in section 6.2.1. Review detailed stakeholder analysis as shown in section 6.2.2. The expectation is that these tasks should take in the region of 1 to 4 weeks to complete.

6.2.1 Definitions and Assumptions

The key definitions and assumption are defined in Table [6-1].

6.2.2 Detailed Stakeholder Analysis

6.2.2.1 Internal Stakeholder Analysis

Internal stakeholders are identified as shown in Table [6-2], where a description of each internal stakeholder is defined, together with Supplier, Input, Processes, Outputs, and Customers (SIPOC) analysis is performed.

6.2.2.2 External Stakeholder Analysis

External stakeholders are identified as shown in Table [6-3], together with the SIPOC analysis being undertaken.

Table 6-1: Key Design Definitions and Assumptions

Attribute	Sub-Attribute	Definition	Applicability	Key Activities
Chemical Regulations.	• Regulators.	• Control and limit the amount of hazardous chemicals in use across society.	• Chemicals placed onto a given marketplace.	• (i) Examine chemicals used within an organisation; (ii) identify potential business continuity risks; (iii) report the presence of a hazardous substance to downstream users; (iv) perform applicable notifications to regulators; (v) request approvals (if applicable) for the continued use of substance(s).
	• Chemicals of concern.	• A chemical considered to be hazardous and of concern.	• Articles (products) that consume chemical substances.	
Quality Management System.	• Procedures and policies.	• Define procedures and policies to ensure consistent norms.	• AS9100 is the accredited QMS system for AD sector (AS9100 Wikipedia, 2020; EASA, 2020).	• (i) *Configuration management: d*rawings, configurations, specifications, materials, methods of manufacture and assembly; (ii) *Certification:* product testing, supporting evidence, etc.
Article (product).	• Physical or virtual form.	• (i) Service, or; (ii) physical item / article.	• Articles are produced to derive some form of economic gain.	• (i) Design documentation; (ii) Raw materials; (iii) Manufacture; (iv) Test; (v) Sales and distribution; (vi) End consumer use; (vii) Maintenance; (viii) Disposal. • Extract article numbers, article names; geometry drawings; specification and related chemical substance information from engineering design and materials definition systems. • Identification of Article number to LLP status.
AD articles (products).	• Articles that operate on land, sea, and air.	• Defined by drawings, specifications, requirements.	• Articles may be: (i) Internally defined; (ii) Customer defined; (iii) Industry defined, and; (iv) Supplier defined. • Typical article lifecycle status: (i) Work in Progress (WIP); (ii) pre-released; (iii) Released and (iv) Obsolete. • New AD article numbers assigned based on changes to FFF to an existing article number. • Articles can be: (i) Very Complex Objects (VCO) > 20K AD article numbers, and; (ii) Extremely Complex Objects (ECO) for example aircraft where there are > 1M AD article numbers (ASD, 2017).	
	• Simple article.	• A single article.		
	• Complex article.	• Two or more simple articles numbers combined to produce a complex object.		
	• Lifecycle status.	• Status of a simple AD article number / complex AD object.		
	• Fit, Form, Function (FFF).	• Key design attributes for a given article.		
	• Geometry drawings.	• Define the geometry of an AD article.		
	• Specifications.	• (i) *Materials:* chemicals which appear on the finished article; (ii) *Process:* chemicals used in the manufacturing process.		
	• Industry standards.	• Define specific functionality and substances, mixtures, and materials.	• (i) Material standards such as metals, paints, etc.; (ii) Article standards such as: nuts, bolts, washers, etc.	

Attribute	Sub-Attribute	Definition	Applicability	Key Activities
	• Life Limited Part (LLP)	• Articles that are considered as critical and are replaced at specific intervals.	• Upon completion of defined periods of use, these article numbers must be removed and replaced by new articles.	
Article (product) certification.	• Type certificate.	• Detailed analysis of design documentation, aircraft flight tests, etc. • Aircraft test flights. • Airworthiness body awards type certificate approval of aircraft.	• All AD aerospace sector products (EASA, 2020). • Upon certification products are subject to strict change control procedures.	• Identification of type certification basis. • Identification of type environmental protection requirements. • Review of type design, covering configuration, design, specifications, materials, methods of manufacture & assembly. • Demonstrate compliance by providing data on testing and supporting evidence.
Buyer-Supplier relationships	• Contractual terms.	• Agreed terms between a buying and supplier organisation.	• Purchase agreement.	• Obligations to request and report data are agreed between a buyer and a supplier. • Clear contract language: (i) Chemical regulations to be reported against; (ii) Frequency of data provision; (iii) The format(s) in which the data needs to be presented; (iv) additional supporting documentation such as external laboratory material test reports.
	• Requesting chemical substance data from the supply chain.	• Rules against which supply chain data will be requested.	• IEC 63000 (IEC, 2018) provides a framework for requesting, receiving, and validating materials related data from the supply chain.	
	• Validation of data from a supplier.	• Rules against which supply chain data will be validated.		

Table 6-2: Internal Stakeholder SIPOC Analysis

Stakeholder *(function)*	**Description** *(role)*	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
Investors / Shareholders	Invest money.	N/A.	Financial / share price performance.	Review data.	Financial investment.	Stock traders. Direct investment into AD organisation.
Human Resources.	Hire employees; Manage employee related issues.	Applicable functional areas requiring resources.	Resource requirements.	Hire / recruit permanent or temporary employees.	Contract of employment; Financial commitments for employee costs.	Applicable functional areas requiring resources.
Employees.	Provide labour and skills to fulfil requirements.	Applicable functional areas requiring resources.	Labour, skills, knowledge. Perform tasks based on knowledge and skills.			

Stakeholder *(function)*	**Description** *(role)*	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
Materials.	Define the chemical substances, mixtures and materials used to produce articles.	Suppliers of chemical substances, mixtures, materials, and articles.	SDS sheets. Supplier specifications. Customer requirements.	Define chemical substances within in material and process specifications.	Material / process specifications. Safe use guidance. Disposal instructions.	Design, Health, Safety & Environment (HSE), engineering, manufacturing, supply chain and compliance.
Design.	Design products.	Materials.	Material / process specifications. Industry standards. Customer requirements.	Define the fit, form and function of products.	Geometry drawings.	Engineering, supply chain and customers.
Engineering.	Define how articles and services are produced.	Materials, design, HSE and quality.	Geometry drawings.	Examine geometry drawings to determine how to produce articles.	Machine programs. Testing procedures. Inspection procedures.	Manufacturing, supply chain, HSE, quality and compliance.
Manufacturing.	Transform raw materials into finished articles.	Design, engineering, and sales.	Raw materials. Manufacturing resources (people, machines)	Machining, test, and inspection processes.	Manufactured products that are tested and inspected to meet requirements.	HSE, quality and compliance.
Purchasing.	Responsible for all organisational purchasing decision making.	Design, engineering, and sales.	Resource requirements from ERP system.	Make / buy decision making. Contractual terms. Supplier assessments.	Agreed supplier criteria, contractual terms, and remedial actions.	Manufacturing, HSE, quality and compliance.
Stores / Transportation.	Receipt, store and allocate supply chain sourced articles.	Suppliers, manufacturing, compliance, technical publications, and sales.	Chemical substances, mixtures, materials, and articles.	Receipt articles and documentation.	Distribution of articles internally. Package articles and arrange transportation.	Materials, manufacturing, HS, quality, compliance, distributors and consumers.
Quality.	Ensure consistent procedures across all functional areas.	All functional areas within the organisation.	Standard operating procedures.	Investigate procedural issues as they arise.	Enforcement of procedures.	All functional areas within the organisation.

Stakeholder *(function)*	**Description** *(role)*	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
HSE.	Ensure the safety and protection of employees, consumers, and the environment.	All functional areas within the organisation.	SDS sheets. Internal / supplier / customer specifications.	Work with materials function to assess the use of chemicals.	Standard operating procedures, safe use guidance, handling, and disposal instructions. Enforcement of procedures.	All functional areas within the organisation.
Accounting and Finance.	Manage organisational cash-flow.	All functional areas within the organisation.	Direct costs: labour, machining. Indirect costs: non-manufacturing costs.	Manage organisational cashflow.	Cost models used to support internal make / buy decision making. Financial accounts.	All functional areas within the organisation.
Marketing.	Generate the customer demand for articles and / or services.	Manufacturing, compliance, HSE, and quality.	article related data: performance, quality, safety, environmental compliance.	Identify article superiority and differentiation.	Marketing publications: online and printed media.	Sales.
Sales.	Maintain customer relationships and generate new sales.	Manufacturing, compliance, HSE, and quality.	Understand customer demand for articles and services.	Maintain supplier-buyer relationship.	Generate of sales orders for articles and services.	Accounting and Finance, Purchasing, Stores / Transportation and Manufacturing.
Technical Publications.	Generate the technical documentation for supplied articles and / or services.	HSE, materials and compliance.	Information on which articles contain hazardous chemicals.	Locational data of applicable articles and standardised safety statements.	Technical documentation that supports the installation and maintenance of supplied articles.	Compliance, sales, and downstream users.
Compliance.	Maintain compliance to applicable environmental and product regulations.	All functional areas within the organisation – in terms of articles procured, defined, ordered from the supply chain, and provided to end consumers.	Substances and reporting obligations as defined in regulations. Article definitions. Supply chain chemical substance reporting data.	Analyse data from internal and external sources to identify compliance scope. Request chemical substance reporting information from	Notifications to regulators (if applicable). Generate compliance statements provided to downstream users for articles sold.	All functional areas within the organisation.

Stakeholder *(function)*	**Description** *(role)*	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
			SDS sheets. Test reports.	the supply chain for procured articles.		

Table 6-3: External stakeholder analysis

Stakeholder group	**Stakeholder group members**	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
Chemical manufacturers.	• Chemical extractors. • Chemical manufacturers. • Chemical importers. • Chemical formulators. • Chemical compounders. • Chemical mixture manufacturers. • Material manufacturers.	• Other chemical extractors and manufacturers (as applicable).	• Chemical regulations (EU REACH, TSCA, CEPA, California Prop 65, etc.). • Labelling regulations (UN GHS, EU CLP).	• Identify hazardous chemicals. • Create new chemicals. • Investigate non-hazardous chemicals.	• Safety data sheets (SDS). • Compliance statements. • Safe use instructions. • Disposal instructions.	• Specialist processes. • Specialist services. • Manufacturing supply chain.
Specialist processes and services.	• Machining. • Bonding. • Heat Treatment. • Plating. • Tools and tooling providers. • Surface finishing. • NDT testing and inspection. • Certification services.	• Chemical • Manufacturing supply chain.	• List of identified hazardous chemicals (regulations and industry standards).	• Identify hazardous chemicals.	• Compliance statements. • Safe use instructions.	• Manufacturing supply chain.
Movement of materials and products.	• Exporters. • Importers. • Distributors. • Stockist. • Transportation. • Fuel providers.	• Chemical manufacturers. • Specialist processes. • Specialist services. • Manufacturing supply chain.	• Regulations and standards.	• Identify hazardous chemicals.	• Compliance statements. • Safe use instructions. • Disposal instructions.	• Chemical manufacturers. • Specialist processes. • Specialist services. • Manufacturing supply chain. • End consumers.
	• Part / Product design service. • Build to print manufacturers.	• Chemical manufacturers.	• List of identified hazardous	• Identify hazardous chemicals.	• Compliance statements.	• OEMs. • MROs.

Stakeholder group	**Stakeholder group members**	**Suppliers** *(to stakeholder)*	**Inputs**	**Processes**	**Outputs**	**Customers** *(of stakeholder)*
AD manufacturing supply chain.	• Component manufacturers. • Semi-component manufacturers. • Equipment manufacturers. • AD article manufacturers. • AD article assemblers. • Assembly manufacturers. • Original Equipment Manufacturers (OEMs).	• Specialist processes. • Specialist services.	chemicals (regulations and industry standards).		• Safe use instructions. • Disposal instructions.	• Airline operators. • Aircraft lessors.
End consumers.	• Airline operators. • Aircraft lessors. • Airfreight couriers. • Private users. • Defence (air, land, sea).	• AD manufacturing supply chain.	• AD articles.	• Identify hazardous substances.	• Compliance statements. • Safe use instructions. • Disposal instructions.	• Users of AD articles.
Competition	• Other AD sector companies supplying same products within the sector.	• AD manufacturing supply chain.	• List of identified hazardous chemicals (regulations and industry standards).	• Identify hazardous chemicals. • AD article differentiation.	• Competing articles. Reduced profitability as alternative AD articles exist.	• OEMs. • MROs. • Airline operators. • Aircraft lessors.
Financial	• Bank / Lenders. • Insurance providers.	• Financial institutions.	• Financial performance. • Share price performance.	• Review data.	• Financial investment(s). • Insurance.	• The AD organisation.
Maintenance, Repair and Overhaul (MRO).	• AD Article refurbishment.	• Chemical manufacturers. • OEMs. • Airline operators. • Aircraft lessors.	• List of identified hazardous chemicals (regulations and industry standards).	• Identify hazardous chemicals.	• Compliance statements. • Safe use instructions. • Disposal instructions.	• OEMs. • Airline operators. • Aircraft lessors.
Regulators and authorities.	• Airworthiness.	• Civil society. • Consumers • Media. • Industry.	• Awareness of hazardous substances.	• Assess the impacts of using hazardous chemicals.	• Monitor and control the use of hazardous chemicals.	• Civil society. • Consumers • Media. • Industry.

6.3 [RQ2] How should AD actors (internal and supply chain) and data elements be conceptualised in a framework?

This question addresses the initial DESIGN phase activities. Review technical design documentation in section 6.3.1. The data model is presented in section 6.3.2. The expectation is that these tasks should take in the region of 2 to 4 weeks to complete.

6.3.1 Technical Design Documentation

This section describes the technical design documentation generated to support the data model, data load templates, and system output reports that highlight potential risks from chemical regulations, which underpins the Conceptual Framework. Figure [6-2] depicts the Technical Design documentation generated as part of this research study. The detailed technical design documentation is presented in Appendix [18].

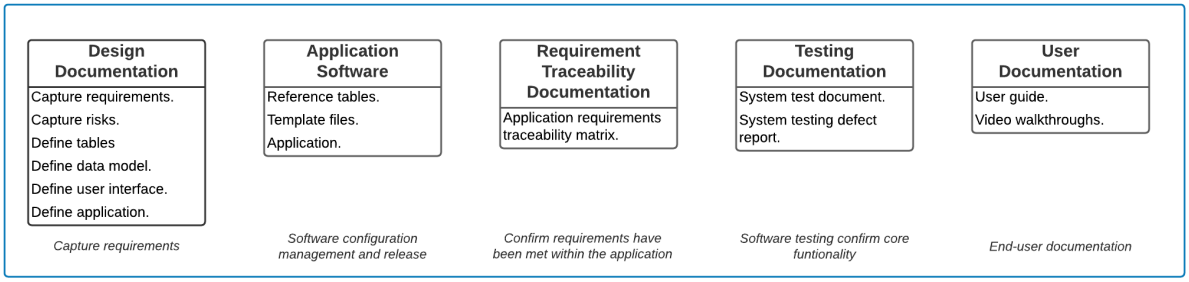


Figure 6-2: Technical Design Documentation

6.3.2 Data Model

The data model in the context of this research study, depicts an overarching set of connected data tables that store discrete data, which may be linked by key fields shared amongst several data table(s). The data model design evolved from: (1) initial research papers analysing the flow of information and proposed data fields (Takhar and Liyanage, 2017a; Takhar and Liyanage, 2017b; Takhar and Liyanage, 2018a; Takhar and Liyanage, 2018c); (2) the conceptual framework design proposed in Chapter 4, and; (3) findings from Delphi Study 1 which attempted to validate the proposed data model as shown in Chapter 5.

6.3.2.1 High-Level Data Model

Figure [6-3] depicts the high-level data model. The high-level data model shows the relationships between different tables where one record from one table may result in multiple records in another, known as one-to-many records.

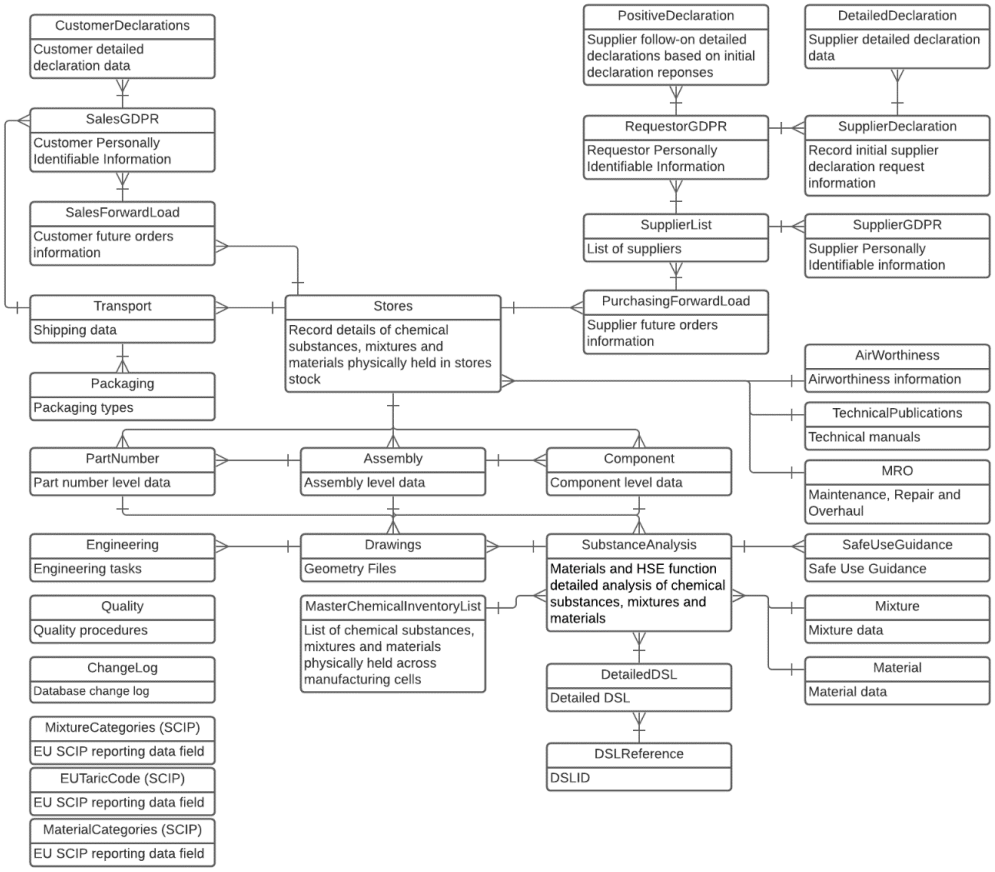


Figure 6-3: High-Level Data Model

6.3.2.2 Substance Level Data Tables

Figure [6-4] presents structure of the tables that define substance level information, where the main table is seen as the SubstanceAnalysis table. Note the **bold** text in the tables represents data fields that cross-reference data fields in other tables, these relationships may be implemented as key fields in a traditional relational database design.

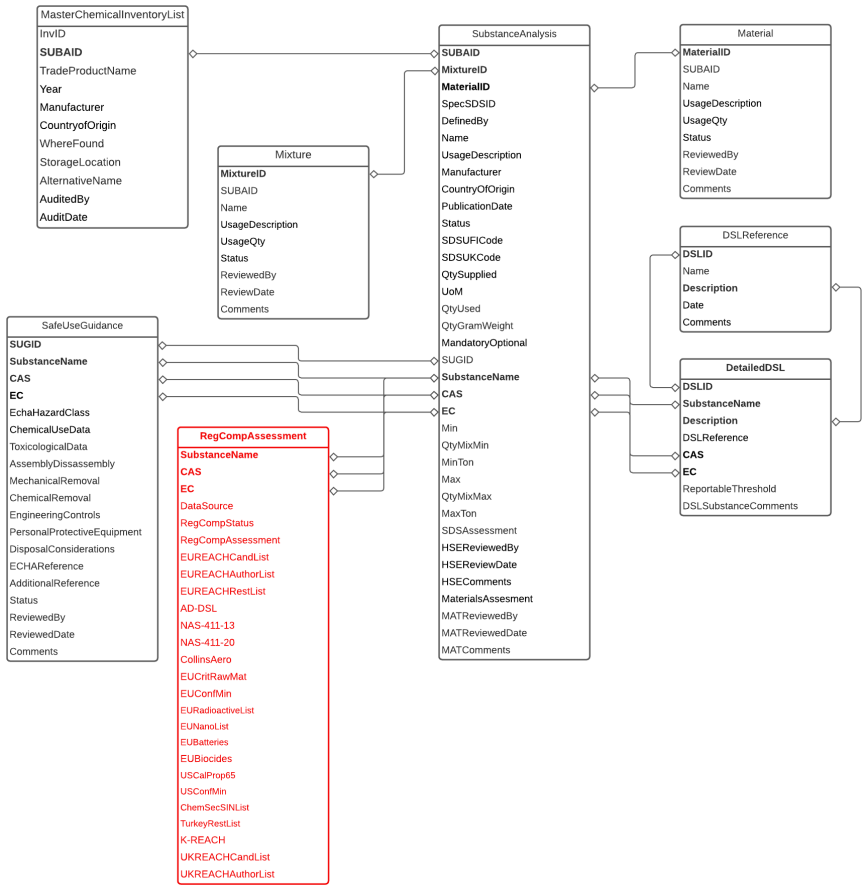


Figure 6-4: Substance Level Data Tables

Appendix [2] presents a detailed breakdown of the Substance Level data fields, and which functions are responsible for data maintenance.

6.3.2.3 Article Level Data Tables

The component, part number and assembly tables follow the same structure, Figure [6-5] presents structure of the tables that define the chemical substances associated to articles, in terms of: (1) being defined via drawings and specifications, or; (2) defined as a specification directly to the article number with no drawing.

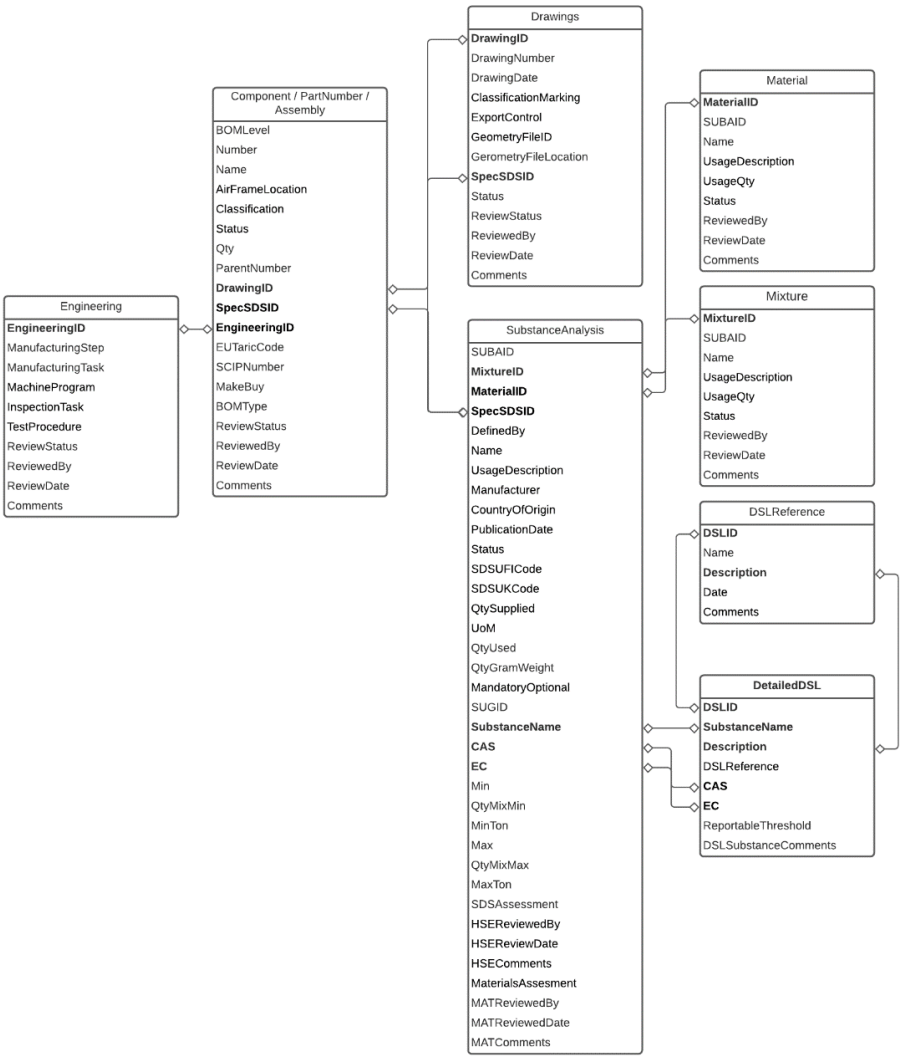


Figure 6-5: Article Level Data Tables

Appendix [3] presents a detailed breakdown of the article level data fields, and which functions are responsible for data maintenance.

6.3.2.4 Supplier Related Data Tables

Figure [6-6] presents structure of the tables that relate to suppliers.

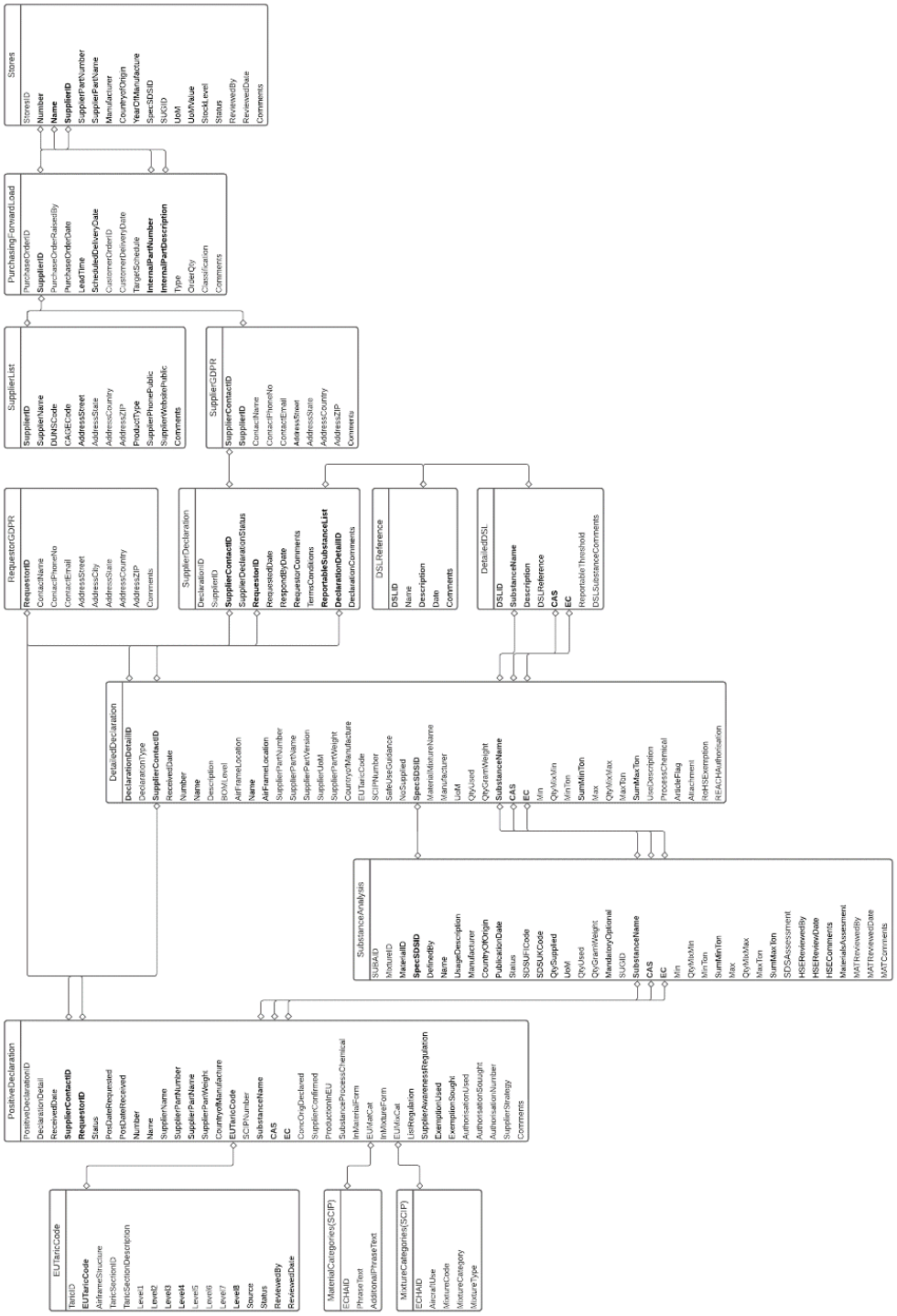

Stores
StoresID
Number
Name
SupplierID
SupplierPartNumber
SupplierPartName
Manufacturer
CountryofOrigin
YearOfManufacture
SpecSDSID
SUCID
UoM
UoMValue
StockLevel
Status
ReviewedBy
ReviewedDate
Comments
PurchasingForwardLoad
PurchaseOrderID
SupplierID
PurchaseOrderRaisedBy
PurchaseOrderDate
LeadTime
ScheduledDeliveryDate
CustomerOrderID
CustomerDeliveryDate
TargetSpSchedule
InternalPartNumber
InternalPartDescription
Type
OrderQty
Classification
Comments
SupplierList
SupplierID
SupplierName
DUNSCode
CAGECode
AddressStreet
AddressState
AddressCountry
AddressZIP
ProductType
SupplierPhonePublic
SupplierWebsitePublic
Comments
SupplierGDPR
SupplierContactID
SupplierID
ContactName
ContactPhoneNo
ContactEmail
AddressStreet
AddressState
AddressCountry
AddressZIP
Comments
RequestorGDPR
RequestorID
ContactName
ContactPhoneNo
ContactEmail
AddressStreet
AddressCity
AddressState
AddressCountry
AddressZIP
Comments
SupplierDeclaration
DeclarationID
SupplierID
SupplierContactID
SupplierDeclarationStatus
RequestorID
RequestedDate
RespondByDate
RequestorComments
TermsConditions
ReportableSubstanceList
DeclarationDetailID
DeclarationComments
DSLReference
DSLID
Name
Description
Date
Comments
DetailedDSL
DSLID
SubstanceName
Description
DSLReference
CAS
EC
ReportableThreshold
DSLSubstanceComments
DetailedDeclaration
DeclarationDetailID
DeclarationType
SupplierContactID
ReceivedDate
Number
Name
Description
BOMLevel
AirFrameLocation
Name
AirFrameLocation
SupplierPartNumber
SupplierPartName
SupplierPartVersion
SupplierUoM
SupplierPartWeight
CountryofManufacture
EUTaricCode
SCIPNumber
SafeUseGuidance
NoSupplied
SpecSDSID
MaterialManufacturerName
ManufacturerUoM
QtyUsed
QtyGramWeight
SubstanceName
CAS
EC
Min
QtyMixMin
MinTon
SumMinTon
Max
QtyMixMax
MaxTon
SumMaxTon
UseDescription
ProcessChemical
ArticleFlag
Attachment
RoHSExemption
REACHAuthorisation
SubstanceAnalysis
SUBAID
MixtureID
MaterialID
SpecSDSID
DefinedBy
Name
UsageDescription
Manufacturer
CountryOfOrigin
PublicationDate
Status
SDSUFICode
SDSUKCode
QtySupplied
UoM
QtyUsed
QtyGramWeight
MandatoryOptional
SUCID
SubstanceName
CAS
EC
Min
QtyMixMin
MinTon
SumMinTon
Max
QtyMixMax
MaxTon
SumMaxTon
SDSAssessment
HSERreviewedBy
HSERreviewDate
HSEComments
MaterialsAssesment
MATReviewedBy
MATReviewedDate
MATComments
PositiveDeclaration
PositiveDeclarationID
DeclarationDetail
ReceivedDate
SupplierContactID
RequestorID
Status
PrdDateRequested
PrdDateReceived
Number
Name
SupplierName
SupplierPartNumber
SupplierPartName
SupplierPartWeight
CountryofManufacture
EUTaricCode
SCIPNumber
SubstanceName
CAS
EC
ConcOrgDeclared
SupplierConfirmed
ProductionEU
SubstanceProcessChemical
InMaterialForm
EUMatCat
InMixtureForm
EUMixCat
ListRegulation
SupplierAwarenessRegulation
ExemptionUsed
ExemptionSought
AuthorisationUsed
AuthorisationSought
AuthorisationNumber
SupplierStrategy
Comments
EUTaricCode
TaricID
EUTaricCode
AirframeStructure
TaricSectionID
TaricSectionDescription
Level1
Level2
Level3
Level4
Level5
Level6
Level7
Level8
Source
Status
ReviewedBy
ReviewedDate
MaterialCategories(SCIP)
ECHAID
PhraseText
AdditionalPhraseText
MixtureCategories(SCIP)
ECHAID
AircraftUse
MixtureCode
MixtureCategory
MixtureType

Figure 6-6: Supplier Level Data Tables

Appendix [4] presents a detailed breakdown of the supplier level data fields, and which functions are responsible for data maintenance.

6.3.2.5 Customer Level Data Tables

The customer level tables are shown in Figure [6-7].

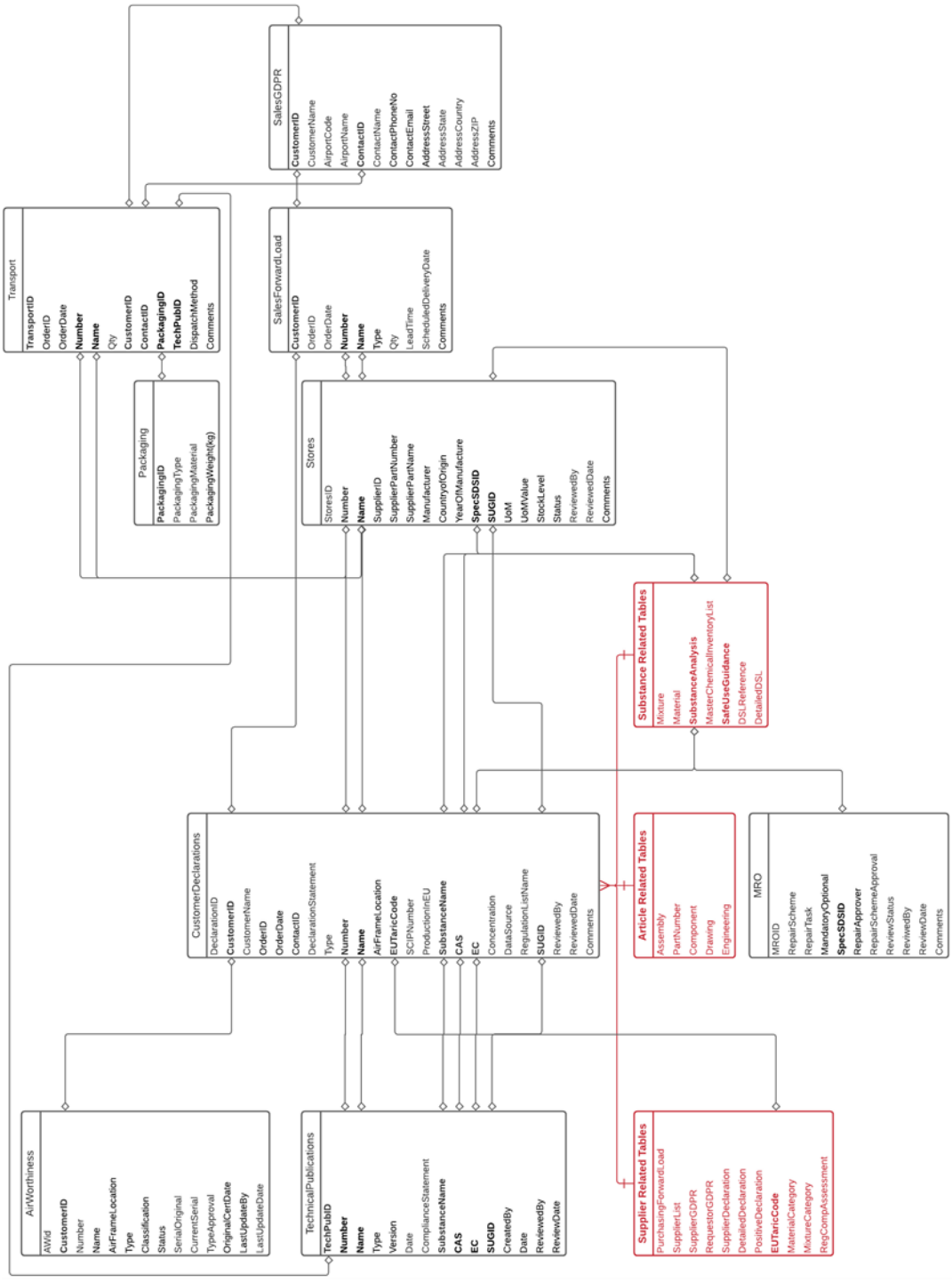


Figure 6-7: Customer Level Data Tables

Appendix [5] presents a detailed breakdown of the customer level data fields, and which functions are responsible for data maintenance.

6.3.2.6 Other Data Tables

Additional tables used to support the application are shown in Figure [6-8].

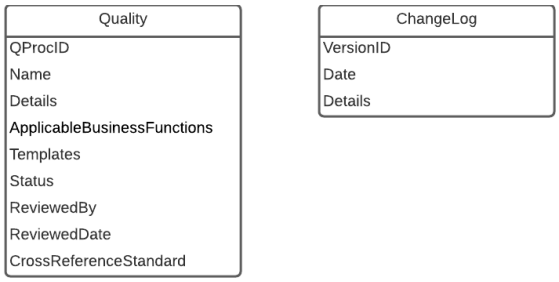


Figure 6-8: Other Related Tables

Appendix [6] presents a detailed breakdown of the other related table data fields, and which functions are responsible for data maintenance.

6.4 [RQ3] How can data be ingested from multiple sub-systems, correlated, reviewed, and assessed in a framework?

This question addresses the initial IMPLEMENT and DEPLOY phase activities. The activities are identified as: review data load templates overview as shown in section 6.4.1. Review the resultant application development section as shown in section 6.4.2. Review the resultant application(s) data processing section as shown in section 6.4.3. Review the data load templates: identifying sources of data as shown in section 6.4.4. Review supply chain data collection as shown in section 6.4.5. The expectation is that these tasks should take in the region of 3 to 6 months to complete.

6.4.1 Data Load Templates Overview

Data is expected to be ingested into the data model, via the use of data load templates which mimic the applicable data table(s) and their data element(s) used to capture data.

6.4.1.1 Overview of Data Load Templates

The data load template files were implemented using MS-Excel spreadsheet files, where the assumption was that the data will be updated and maintained outside the main application by the applicable functional business units. Figure [6-9] depicts the flow of unstructured data being added into MS-Excel template files that: (1) allow for data normalisation using a mixture of data fields containing drop down lists and conditional statements to perform calculations within the MS-Excel template where applicable, and; (2) the application itself

which ingests the MS-Excel template files and; (3) the output reporting from the application that enables output reporting and further actions to be undertaken.

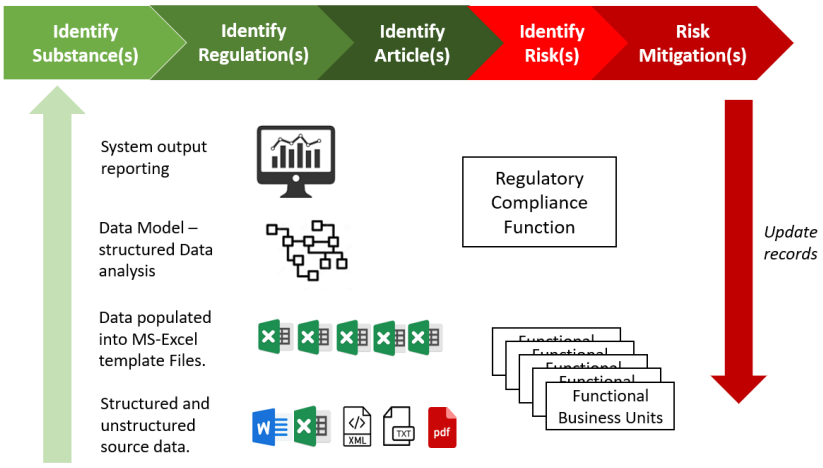


Figure 6-9: Anticipated Data Flows

The design intent was undertaken in contrast to traditional Relational Database Management System (RDMS) methodologies where the data fields may have been developed into specific data classes, methods and contained within the application itself, requiring users to perform data record creation and updates within the resultant applications.

6.4.1.2 Implemented Data Load Templates

This implemented design intent allows for users to add / remove data fields in the template files, adjust any output reporting using simple MS-Excel formula and calculations, which are described in Appendix [19], simple commands were used within the data load templates as opposed to producing a heavily customised application which would require specialist skills to maintain. The implemented template files are shown in Table [6-4].

Table 6-4: Data Load Templates

Template name	**Description**	**Data populated and maintained by**
Airworthiness.	Details of article serial numbers and whether they require any form of aerospace regulatory approval. As new articles are manufactured and released, the data in this table should be updated.	Airworthiness.
Assembly.	Details of assembly definitions capturing details drawing, specification, make/buy and type of BOM for the assembly. To be updated as new assemblies are defined by design and passed to manufacturing for assessment.	Manufacturing.
ChemicalSubstanceInventory.	Details of chemical substances, mixtures and materials held physically across manufacturing cells within an organisation. The chemical substance inventory audit should take place at least on an annual basis and the data in this table should be subsequently updated.	Stores and HSE.
Component.	Details of component definitions capturing details drawing, specification, make/but and type of	Manufacturing.

Template name	Description	Data populated and maintained by
	BOM for the component. To be updated as new components are defined by design and passed to manufacturing for assessment.	
CustomerDeclaration.	Details of any declaration statement made to customers. To be updated as any additional declarations made to customers are identified.	Regulatory Compliance.
DatabaseChangeLog.	Details of any changes undertaken to the application. To be updated as any changes are made to the application.	Regulatory Compliance.
DetailedDeclaration.	Detailed supplier declaration statements requested and received by the Regulatory Compliance function into a standardised format which meets the common data fields used in IPC-1754 data exchange standard format. To be updated as new supplier declarations are received.	Data received from supply chain but maintained by Regulatory Compliance.
DetailedDSL.	Detailed DSL which lists the chemicals of concern against a defined regulatory DSL. As new substances are added to a given DSL, the table should be updated.	Regulatory Compliance.
Drawing	Engineering geometry file ID numbers and / or specific SpecSDSID data. To be updated as new articles are created using internal engineering design systems.	Design.
DSLReference.	Name of a given DSL given a unique ID number. As new DSLs are identified, the DSL name shall be defined in this table with the DetailedDSL table defining the chemical substances assigned to a given DSL.	Regulatory Compliance.
Engineering.	Definition of engineering steps which the manufacturing function or supply chain need to perform to produce articles. To be updated as new engineering steps are defined.	Engineering.
Material.	Details of defined materials. As new materials are utilised, the data in this table shall be updated.	Materials.
Mixture.	Details of defined mixtures. As new mixtures are utilised, the data in this table shall be updated.	Materials.
MRO.	Details of repair schemes and applicable specifications. As new repair specifications are defined, the data in this data should be updated.	MRO.
Packaging.	Details of packaging used to ship articles. To be updated as packaging types are identified.	Stores.
PartNumber.	Details of part number definitions capturing details drawing, specification, make/but and type of BOM for the part number. To be updated as new part numbers are defined by design and passed to manufacturing for assessment.	Manufacturing.
PositiveDeclaration.	A follow-on declaration request to gauge supplier awareness and applicable strategy for managing the use of a chemical of concern within a supplied article. As the initial declarations and entries on the DetailedDeclaration table identify new articles or additional chemicals of concern from supplied articles, then this table shall be updated as the positive declaration is transmitted to a supplier.	Regulatory Compliance.

Template name	Description	Data populated and maintained by
PurchasingForwardLoad.	Future purchase orders for articles procured from the supply chain. The data in this table should be refreshed at least quarterly.	Purchasing.
Quality.	Details of companywide and functional business unit quality procedures and processes. As new quality procedures and processes are raised then the data in this data should be updated.	Quality.
RequestorGDPR.	Details of internal regulatory compliance contacts in a GDPR format table. As new members of the regulatory compliance function, that may transmit requests to suppliers are employed, then the data in this table needs to be updated.	Regulatory Compliance.
SafeUseGuidance.	Safe use guidance statements specific to chemicals of concern to be utilised making customer declarations and applicable entries in a technical publication. To be updated as new chemicals of concern are identified in articles.	HSE.
SalesForwardLoad.	Details of future sales orders of articles sold and which customers placed a sales order. This view provides an indication of how many affected articles with a chemical of concern are order with a given customer. As new sales orders are raised then the data in this data should be updated. The data in this table should be refreshed at least on a quarterly basis.	Sales.
SalesGDPR.	Details of customer contacts in a GDPR format table which may be restricted from view within the application. As new customers are introduced and / or new contact details from existing customer, the data in this table should be updated.	Sales.
SCIPEUTaricCodes.	Details of current EU Taric codes extracted as applicable to the aerospace sector. The accounting function will need to review existing EU Taric codes and update the data in this table accordingly.	Accounting.
SCIPMaterialCategories.	ECHA SCIP material category data extracted from the ECHA SCIP database. The data will need to be extracted on an annual basis at the end of October as ECHA release the updated database software code. This will result in the need to update the data in this table accordingly.	Regulatory Compliance.
SCIPMixtureCategories.	ECHA SCIP mixture category data extracted from the ECHA SCIP database. The data will need to be extracted on an annual basis at the end of October as ECHA release the updated database software code. This will result in the need to update the data in this table accordingly.	Regulatory Compliance.
Stores.	Details of chemical substances, mixtures, materials, and articles held physically within the stores warehouse area. To be updated periodically to identify items held in storage.	Stores.
SubstanceAnalysis.	Combined status analysis of specifications, standards and SDSs. To be updated as new specifications, standards and SDSs are identified.	HSE and Materials.
SupplierDeclaration.	Details of initial supplier declaration requests transmitted to suppliers for completion. To be updated as new supplier declarations are requested.	Regulatory Compliance.

Template name	Description	Data populated and maintained by
SupplierGDPR.	Details of supplier contacts in a GDPR format table which may be restricted from view within the application. As new suppliers are introduced and / or new contact details from existing suppliers the data in this table should be updated.	Purchasing and Regulatory Compliance.
SupplierList.	Detailed supplier list. To be updated as new suppliers are being added by the purchasing function.	Purchasing.
TechnicalPublications.	Details of technical publications statements made in relation to identified chemicals of concern on articles. As new articles requiring statements are identified, the data in this table should be updated.	Technical Publications.
Transport.	Identification of how articles are shipped to customers. The data in this table should be refreshed on a quarterly basis at least.	Stores.

6.4.1.3 Data Load Templates Specific to Chemical Regulations

This section describes the chemical regulation reportable substance lists identified, where the data load templates: (1) DSLReference contains the DSL ID, name, description, and date last updated, with; (2) DetailedDSL recording the detailed list of chemical substances associated to a DSLID. Table [6-5] describes each regulatory substance list, recorded under both the DSLReference and DetailedDSL data load templates in more detail.

Table 6-5: Chemical Regulations, Substance Lists and Number of Substances

ID	Name	Description	Number of Substances	Source(s)
DSL001	EU REACH Candidate List of Substances.	EU REACH regulation specific substance lists covering (1) reportable substances were identified on finished article (candidate list); (2) controlled substances that require a permit for use (authorisation list), and; (3) restricted substances.	399	ECHA, 2020a.
DSL002	EU REACH Authorisation List of Substances (Annex XIV).		98	ECHA, 2020b.
DSL003	EU REACH Restricted List of Substances (Annex XVII).		875	ECHA, 2020c.
DSL004	EU Restriction of Hazardous Substances List (RoHS) for Electronics.	Identifies chemical substances which are banned by default unless an approved exemption exists to allow for continued used of the banned chemical substances for a specific use context. EU RoHS impacts the AD sector indirectly where electronic component suppliers may remove an article from the marketplace due to RoHS restrictions.	10	EU, 2003; EC, 2011; EU, 2015.
DSL005	EU Nanomaterial Substances List.	EU nanomaterials defined as being in use within the EU, coming under the scrutiny of the EU REACH regulation.	325	EUON, 2019.
DSL006	EU Radioactive Substances List.	Substance list generated by comparing legal text and then cross-referencing isotope numbers to applicable chemical substances.	87	EU, 2013; ATSDR, 2020.

ID	Name	Description	Number of Substances	Source(s)
		The analysis conducted can be viewed in RadioactiveSubstances.		
DSL007	EU Conflict Minerals Substances List (EU CMR).	EU conflict minerals reporting list. Initially implemented with the same minerals as per US CMR, with a much wider number of regions identified for reporting known as CAHRAs.	4	EC, 2020g.
DSL008	EU Persistent Organic Pollutants List (POPS).	EU defined POP substances in line with the globally agreed signatories to the Stockholm convention.	202	ECHA, 2020d.
DSL009	Critical Raw Materials for AD sector.	US Geological Society assessment of chemical substances that impact the different, analysis was based on US CRM list of 2017, which has the same chemical substances defined as the EU CRM list.	56	USGS, 2018.
DSL010	Critical Raw Materials for Electronics sector.		59	
DSL011	Critical Raw Materials for Transportation sector.		33	
DSL012	ChemSec Substitute It Now! (SIN) List.	NGO list of substances identified as being hazardous with recommendations to industry phase out use.	1019	Chemsec, 2020.
DSL013	US Conflict Mineral Substances List (US CMR).	US Dodd-Frank Wall Street Reform and Consumer Protection Act 2012 implemented requirements for companies listed on the US stock exchanges to report in their financial accounts (10K, 20F or 40F formats), if certain minerals classed as conflict minerals: Tin, Tantalum, Tungsten and Gold (known as 3TG) minerals sourced from the Democratic Republic of Congo (DRC). Conflict mineral reporting (CMR) has no threshold level.	4	SEC, 2012.
DSL014	IAEG AD Declarable Substance List (AD-DSL.	Declarable substances defined by largest AD companies within an environmental trade association.	1573	IAEG, 2019.
DSL015	EU Batteries Directive.	Batteries directive covering reporting and recycling for 3 substances.	3	EC, 2006b.
DSL016	EU Critical Raw Materials List (EU CRM).	Chemical substances defined as being critical raw materials needed by industry.	52	EU, 2017; EU, 2020.
DSL017	EU Biocidal Products Regulation List of Approved Active Substances (EU BPR).	Control of active ingredients for biocidal products, which allows for only approved active substances from approved active substance manufacturers to be used in the EU.	164	EC, 2012b.
DSL018	US TSCA Low-Priority Substances List.	Substances being consulted on and reviewed as part of future updated to US TSCA.	36	TSCA Wiki, 2020
DSL019	US TSCA List of Chemicals Undergoing Risk Evaluation.		20	

ID	Name	Description	Number of Substances	Source(s)
DSL020	US California Prop 65.	Chemical substances that need to be reported against for articles sold to consumers and used in the workplace. Prop 65 whilst California specific, is used widely within compliance requirements across the US.	883	OEHHA, 2020
DSL021	US NAS 411-1 (September 2013).	US DoD reportable substance list which is to be reported against as part of a Hazard Materials Management Program (HMMP) for products and services sold to the US military services.	1043	AIA, 2016
DSL022	EU Regulatory Management Option Analysis (RMOA) substances awaiting further action	Substances currently under review by ECHA but not fully assessed, potential substances which may come under the radar of chemical regulators.	260	ECHA, 2020e.
DSL023	Turkey Annex 17 Restricted Substances List.	Turkey KKDIK (REACH) establishes Annex 17 as a list of chemical substances restricted in Turkey. 67 entries listed in Annex 17 were broken out into 105 individual substances.	105	ChemicalWatch, 2020
DSL024	South Korea K-REACH Restricted Substances List.	Restricted substances in South Korea.	653	CIRS, 2019.
DSL025	Canada Toxic Substances List.	Substances identified as most hazardous and regulated for industry to phase out.	26	Government of Canada, 2019.
DSL026	EU REACH Candidate List of Substances Non-Exhaustive Expanded Substances.	EU REACH substance groups expanded from substance groups. Data was extracted from ECHA documents showed the initial review and classification of SVHC chemicals, which showed similar chemicals meeting the same hazardous properties criteria.	485	ECHA, 2020a.
DSL027	EU Restriction of Hazardous Substances List (RoHS) for Electronics Non-Exhaustive Expanded Substances.	EU RoHS substance groups expanded from substance groups.	1008	EU, 2003; EC, 2011; EU, 2015.
DSL028	Collins Aerospace: Materials of Concern List.	Large AD OEM defined list of reportable chemical substances derived from several chemical regulations.	2513	Collins Aerospace, 2020a.
DSL029	US NAS 411-1 Tracked Substances List (October 2020).	See DSL021.	121	IHS, 2020.
DSL030	EU Fluorinated Gas Regulation No 517/2014 (EU F-GAS).	Control of specific types of greenhouse gases.	93	EU, 2014.
DSL031	EU Biocidal Products Regulation List of Pending Active Substances (EU BPR).	List of pending active ingredients under EU BPR.	497	EC, 2012b.

ID	Name	Description	Number of Substances	Source(s)
DSL032	EU Biocidal Products Regulation List of Cancelled Active Substances (EU BPR).	List of cancelled active ingredients under EU BPR.	140	
DSL033	US NAS 411-1 Restricted Substances List (October 2020).	See DSL021.	527	IHS, 2020.
DSL034	US NAS 411-1 Prohibited Substances List (October 2020).		587	
DSL035	US TSCA Persistent Bioaccumulative and Toxic (PBT) Chemicals Under TSCA Section 6(h).	Chemicals defined as specific restrictions on their own, in mixtures and in articles.	5	EPA, 2021.
DSL036	UK REACH Candidate List of Substances.		303	HSE, 2021a.
DSL037	UK REACH Authorisation List of Substances.		95	HSE, 2021b.

6.4.1.4 Data Load Templates Which May Identify the Impacts of Chemical Regulations

The chemical regulation substances shown in the previous section were categorised into a traffic light system to highlight the potential risks of a given regulated chemical substance identified against an AD article. Table [6-6] was generated to aid the identification of risks within the database application.

Table 6-6: Chemical Regulation Substance Lists Grouped in Terms of Potential Impact and Risk

ID	Name	Impact Status	Risk Colour
Tracked substances – Chemical regulations that require substances to be identified, reported to downstream users and where applicable notifications submitted to a regulator.			
DSL001	EU REACH Candidate List of Substances.	1. Monitor substances on these lists. 2. Launch investigation into the use of alternative substances.	
DSL005	EU Nanomaterial Substances List.		
DSL007	EU Conflict Minerals Substances List (EU CMR).		
DSL009	Critical Raw Materials for AD sector.		
DSL010	Critical Raw Materials for Electronics sector.		
DSL011	Critical Raw Materials for Transportation sector.		
DSL012	ChemSec Substitute It Now! (SIN) List.		
DSL013	US Conflict Mineral Substances List (US CMR).		
DSL014	IAEG AD Declarable Substance List (AD-DSL).		
DSL015	EU Batteries Directive.		
DSL016	EU Critical Raw Materials List (EU CRM).		
DSL018	US TSCA Low-Priority Substances List.		
DSL019	US TSCA List of Chemicals Undergoing Risk Evaluation.		

ID	Name	Impact Status	Risk Colour
DSL020	US California Prop 65.		
DSL021	US NAS 411-1 (September 2013) *[Legacy list version]*.		
DSL022	EU Regulatory Management Option Analysis (RMOA) substances awaiting further action.		
DSL026	EU REACH Candidate List of Substances Non-Exhaustive Expanded Substances		
DSL028	Collins Aerospace: Materials of Concern List		
DSL029	US NAS 411-1 Tracked Substances List (October 2020)		
DSL032	EU Biocidal Products Regulation List of Cancelled Active Substances (EU BPR).		
DSL036	UK REACH Candidate List of Substances		
Authorised substances – Chemical regulations that require substances to be reviewed and approved by a regulator for continued use. Substances on these types of lists should be treated as strong triggers to investigate the use of alternative substances, where no suitable alternative substances are not currently available the authorisation process would be used to enable AD organisations to use the existing authorised substance for a defined period until suitable alternative substances can be reviewed and tested.			
DSL002	EU REACH Authorisation List of Substances (Annex XIV)	1. Understand the use of the chemical substance. 2. Apply for authorisation(s) if required for continued use. 3. Investigate alternative substances, covering article redesign and testing.	
DSL017	EU Biocidal Products Regulation List of Approved Active Substances (EU BPR)		
DSL030	EU Fluorinated Gas Regulation No 517/2014 (EU F-GAS)		
DSL031	EU Biocidal Products Regulation List of Pending Active Substances (EU BPR)		
DSL033	US NAS 411-1 Restricted Substances List (October 2020)		
DSL035	US TSCA Persistent Bioaccumulative and Toxic (PBT) Chemicals Under TSCA Section 6(h).		
DSL037	UK REACH Authorisation List of Substances		
Prohibited substances – Chemical regulations that require restrict / prohibit the use of a chemical substance, either in its entirety or for specific use cases. Substances on this list need to be checked in accordance with the explicit statements pertaining to the condition of restriction defined under for the chemical within the applicable regulation.			
DSL003	EU REACH Restricted List of Substances (Annex XVII).	1. Understand the basis of the restriction. 2. Investigate alternative substances, covering article redesign and testing.	
DSL004	EU Restriction of Hazardous Substances List (RoHS) for Electronics.		
DSL006	EU Radioactive Substances List.		
DSL008	EU Persistent Organic Pollutants List (POPS).		
DSL023	Turkey Annex 17 Restricted Substances List.		
DSL024	South Korea K-REACH Restricted Substances List.		
DSL025	Canada Toxic Substances List.		
DSL027	EU Restriction of Hazardous Substances List (RoHS) for Electronics Non-Exhaustive Expanded Substances.		
DSL034	US NAS 411-1 Prohibited Substances List (October 2020).		

6.4.1.5 Data Load Templates Additional Reference Tables

Prior to the commencement of the data load template population, several reference tables were generated as shown in Figure [6-10] and Table [6-7], the purpose of these specific tables was to support the system analysis and generation of system output reports.

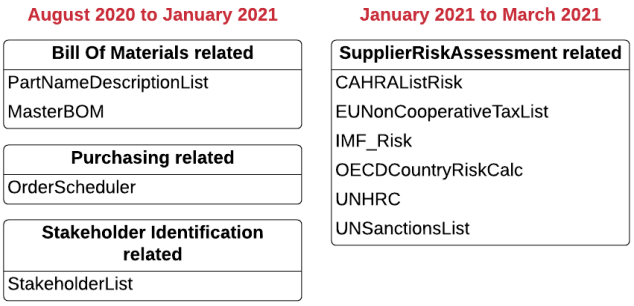


Figure 6-10: Reference Tables

Table 6-7: Reference Tables

Reference table name	Description	Source / number of records
PartNameDescriptionList.	Created using: 1. Data collated from AD companies engaged in earlier Delphi studies; 2. Online searches for specific IETPs enabling the extraction of articles contained within Aircraft BOMs. 20,702 records were collated and examined to generate a representative set of common aircraft article names, which were then referenced in the creation of an aircraft BOM.	• 2 data fields. • 20,702 source articles. • 3,209 common article names.
MasterBOM.	Initial draft Aircraft BOM consisting or assemblies, part numbers, components).	• 172 unique articles defined.
StakeholderList.	List of unique external stakeholders who could be engaged within in the event of a chemical substance being proposed for further regulatory control measures.	• 378 stakeholders.
OrderScheduler.	1,305 working days from placement of initial customer sales order, where OrderScheduler file enables identification of proposed delivery dates for the main assemblies used on the aircraft. Working days based on authors previous experience in the sector.	• 8 data fields. • 27 records.
CAHRAListRisk .	EU list of Conflict Areas and High-Risk Areas. This table was used to compile the data in the SupplierRiskAssessment data load template.	• 3 data fields. • 27 records.
EUNonCooperativeTaxList.	EU list of countries with dubious taxation policies, identifies a risk of money laundering, fraud, etc.	• 5 data fields. • 12 records.
IMF_Risk.	Countries ranked by GDP, unemployment, balance sheet and population size.	• 13 data fields • 201 records.
OECDCountryRiskCalc.	Countries ranked by risk assessment by OECD.	• 6 data fields. • 202 records.

Reference table name	Description	Source / number of records
UNHRC.	List of countries assessed by number of special procedures visits requested.	• 6 data fields. • 188 records.
UNSanctionsList.	List of countries subject to UN sanctions.	• 2 data fields • 11 records.

6.4.2 Resultant Application Development

6.4.2.1 Application UI Storyboards

Application User Interface (UI) storyboards were used to aid the development of the application interface. Figure [6-11] presents the flow of functional menus accessible from the main menu with applicable sub-menus and options, utilising data ingested from data load templates. The detailed storyboards are presented in Appendix [7].

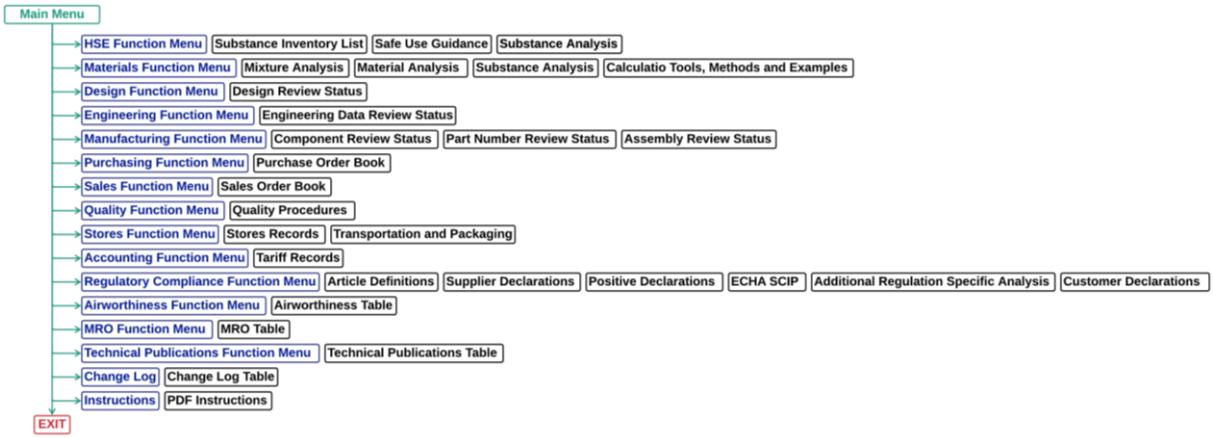


Figure 6-11: Menu Structure Overview

Two resultant applications were created capable of ingesting the data load templates, into the data model, from where system output reporting takes place to identify potential risks posed by chemical regulations.

6.4.2.2 Application 1: Database Application

Local database application, utilising MS-Access. Appendix [8] describes the application perquisites, location of application and data load template file configuration tasks, enabling the database application to perform system output reporting.

6.4.2.3 Application 2: Dashboard Application

Local / Remote dashboard application ingesting, utilising Tableau Desktop / web browser. Remote dashboard application has been published onto the Tableau public servers, which can be accessed via this link that will open the dashboard application and display using a web browser. Local dashboard application can be downloaded using the online link, the run

locally using Tableau desktop application software. Appendix [9] describes the application perquisites, location of application and data load template file configuration tasks, enabling the dashboard application to perform system output reporting.

6.4.3 Resultant Application(s) Data Processing

6.4.3.1 Data Load Templates Used Within Resultant Application(s)

Table [6-8] describes the data load templates consumed in both applications.

Table 6-8: Summary of data load template and system output reports

Data Load Template / System Output Report Name	Database	Dashboard
Data load templates		
AirWorthiness.xlsx.	Yes	Yes
Assembly.xlsx.	Yes	Yes
ChemicalSubstanceInventory.xlsx.	Yes	Yes
Component.xlsx.	Yes	Yes
CustomerDeclarations.xlsx.	Yes	Yes
DashboardChangeLog.xlsx.	-	Yes
DatabaseChangeLog.xlsx.	Yes	-
DetailedDeclaration.xlsx.	Yes	Yes
DetailedDSL.xlsx.	Yes	Yes
Drawing.xlsx.	Yes	Yes
ECHASubInfoCardData.xlsx.	-	Yes
Engineering.xlsx.	Yes	Yes
Material.xlsx.	Yes	Yes
Mixture.xlsx.	Yes	Yes
MRO.xlsx.	Yes	-
Packaging.xlsx.	Yes	Yes
PartNumber.xlsx.	Yes	Yes
PositiveDeclaration.xlsx.	Yes	Yes
PurchasingForwardLoad.xlsx.	Yes	Yes
Quality.xlsx.	Yes	Yes
RegCompAssessment.xlsx.	Yes	Yes
RequestorGDPR.xlsx.	Yes	Yes
SafeUseGuidance.xlsx.	Yes	Yes
SalesForwardLoad.xlsx.	Yes	Yes
SalesGDPR.xlsx.	Yes	Yes
SCIPEUTaricCodes.xlsx.	Yes	Yes
SCIPMaterialCategories.xlsx.	Yes	-
SCIPMixtureCategories.xlsx.	Yes	-
Stores.xlsx.	Yes	Yes
SubstanceAnalysis.xlsx.	Yes	Yes
SupplierDeclaration.xlsx.	Yes	Yes
SupplierGDPR.xlsx.	Yes	Yes
SupplierList.xlsx.	Yes	Yes
SupplierRiskAssessment.xlsx.	-	Yes
TechnicalPublications.xlsx.	Yes	Yes
Transport.xlsx.	Yes	Yes
User selectable menu options		
HSE Function	Yes	Yes
Materials Function	Yes	Yes
Design Function	Yes	Yes
Engineering Function.	Yes	Yes
Purchasing Function.	Yes	Yes
Sales Function.	Yes	Yes
Quality Function	Yes	Yes
Manufacturing Function.	Yes	Yes
Stores Function.	Yes	Yes
Accounting Function.	Yes	Yes
AirWorthiness Function	Yes	Yes

MRO Function	Yes	-
Technical Publications	Yes	Yes
Regulatory Compliance Function	Yes	Yes
Regulatory Compliance Risk Assessment	Yes	Yes
User Guide	Yes	Yes
Change Log	Yes	Yes
About	Yes	Yes
System output report types		
System output reporting: by Substance name.	Yes	-
System output reporting: by CAS number.	Yes	Yes
System output reporting: by EC number.	Yes	-
User selectable regulatory substance list.	Yes	Yes

6.4.3.2 Data Load Templates Ingestion Overview

Figures [6-12] and [6-13] outline the high-level process for ingesting data the data load template files within the applicable resultant application(s).

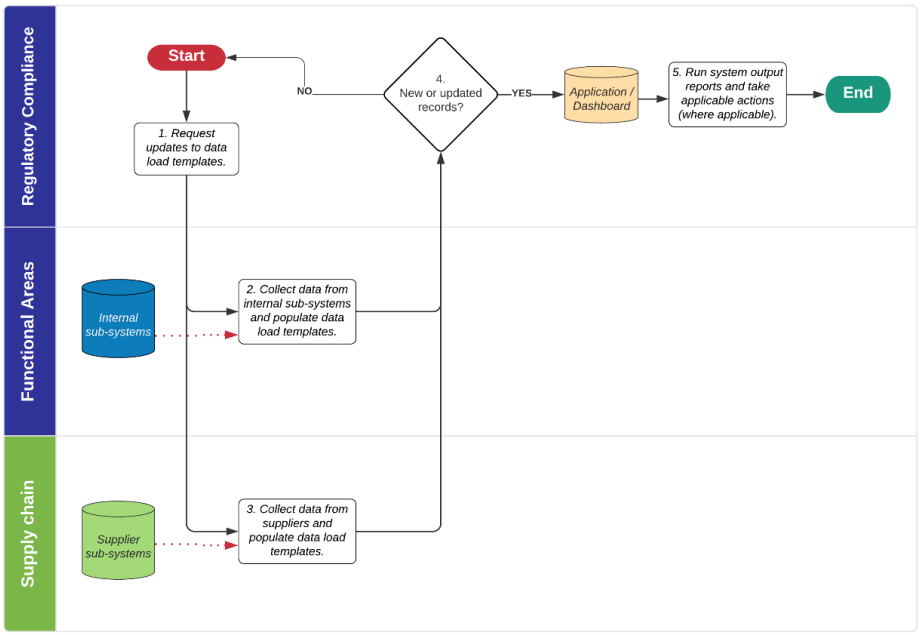
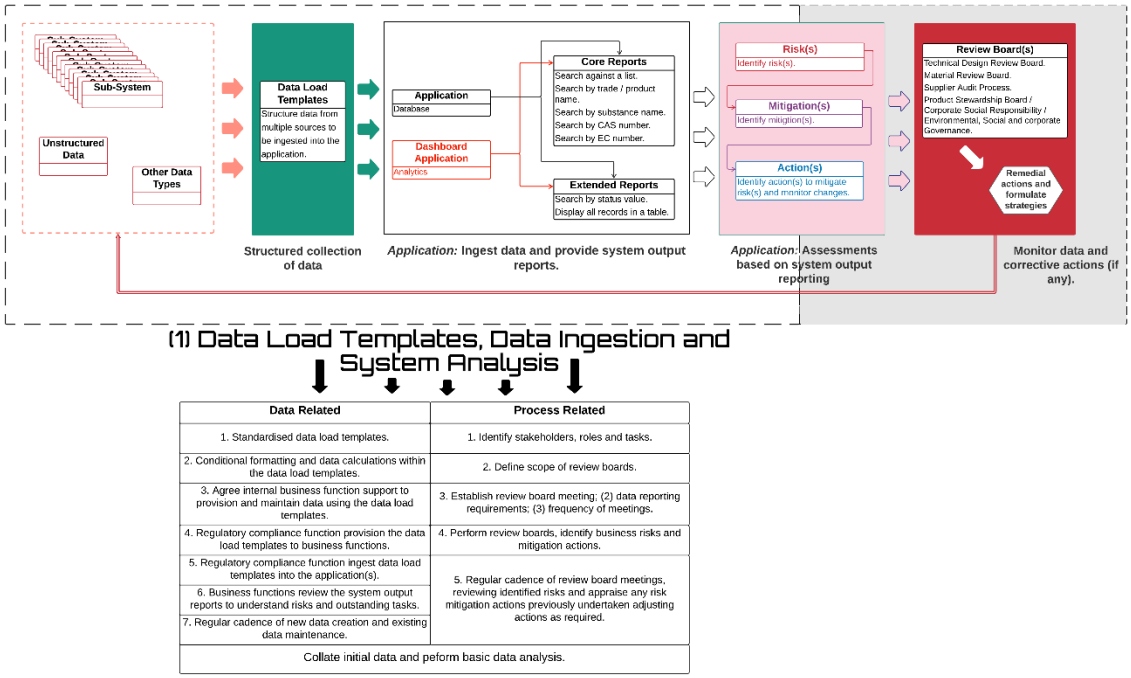


Figure 6-12: Data Load Template Ingestion Process Overview



(1) Data Load Templates, Data Ingestion and System Analysis

Data Related	Process Related
1. Standardised data load templates.	1. Identify stakeholders, roles and tasks.
2. Conditional formatting and data calculations within the data load templates.	2. Define scope of review boards.
3. Agree internal business function support to provision and maintain data using the data load templates.	3. Establish review board meeting; (2) data reporting requirements; (3) frequency of meetings.
4. Regulatory compliance function provision the data load templates to business functions.	4. Perform review boards, identify business risks and mitigation actions.
5. Regulatory compliance function ingest data load templates into the application(s).	5. Regular cadence of review board meetings, reviewing identified risks and appraise any risk mitigation actions previously undertaken adjusting actions as required.
6. Business functions review the system output reports to understand risks and outstanding tasks.	
7. Regular cadence of new data creation and existing data maintenance.	
Collate initial data and peform basic data analysis.	

Figure 6-13: System Analysis Overview

The working assumption is as follows:

- *Unstructured and semi-structured data*: Likely to come from multiple sub-systems and formats as shown in Figure [6-13]. The business function responsible for collating data for specific data load templates shall extract data from source systems.
- *Data load templates*: Business functions with unstructured and semi-structured data shall populate the data load template files, which enable structured data to be processed by the application. The applicable business functional units shall update and maintain the template files, including any status updates for a given record. The status values within the data load templates record the status of a given data record as follows:
    - *ReviewStatus*: This status field is defined on several data load templates (*Assembly*, *Component*, *Drawing*, *Engineering*, *Material*, *Mixture*, *MRO*, *PartNumber*, *PositiveDeclaration*, *Quality*, *SafeUseGuidance*, *Stores*).
        - Any analysis of data shall only select records where the *ReviewStatus* field equals a value of **Reviewed** which denotes that the data has been collated and has been reviewed by an applicable business function.
    - *SupplierDeclarationStatus*: Regulatory Compliance function status field used to track the status of records in supplier declaration requests (SupplierDeclaration).

        - Any analysis of data shall only select records where the *SupplierDeclarationStatus* field equals a value of **Initial Supplier Declaration Completed.**
    - *SDSAssessment* and *MaterialsAssessment*: Used specifically with the SubstanceAnalysis data load template, to denote review activities being conducted by different business functions, where the fields are completed as *SDSAssessment* (HSE) and *MaterialsAssessment* (Materials), where:
        - *SDSAssessment* should have values of **SDS substance assessed awaiting safe use guidance** or **SDS substance assessed safe use guidance created**, where the HSE function has assessed any safe use statements which need to be generated.
        - *MaterialsAssessment* should have a value of **Substance is declarable above 0.1% w/w**, this assumes that the Materials function has reviewed the data and performed a materiality assessment and used
    - *ReviewedBy*: Certain data load templates contain just a *ReviewedBy* field, where the data record has been reviewed as this dataset has been generated based on the output of other system output reports. The applicable data load templates are CustomerDeclarations TechnicalPublications.
- *Application data model*: defines the data model used within the application which ingests the populated data template files.
- *Application system output reports*: the system output reporting generated by the application
- *Additional processing*: Undertaken following the generation of system output reporting as part of further review processes, as shown in the following sub-sections.

The initial assessment is based on identified use of a chemical of concern and with assessments by applicable business functions, shown in the applicable data fields above, providing the basis for establishing reportable chemicals of concern, from internal definitions and supplier declared data, as shown in Figure [6-14].

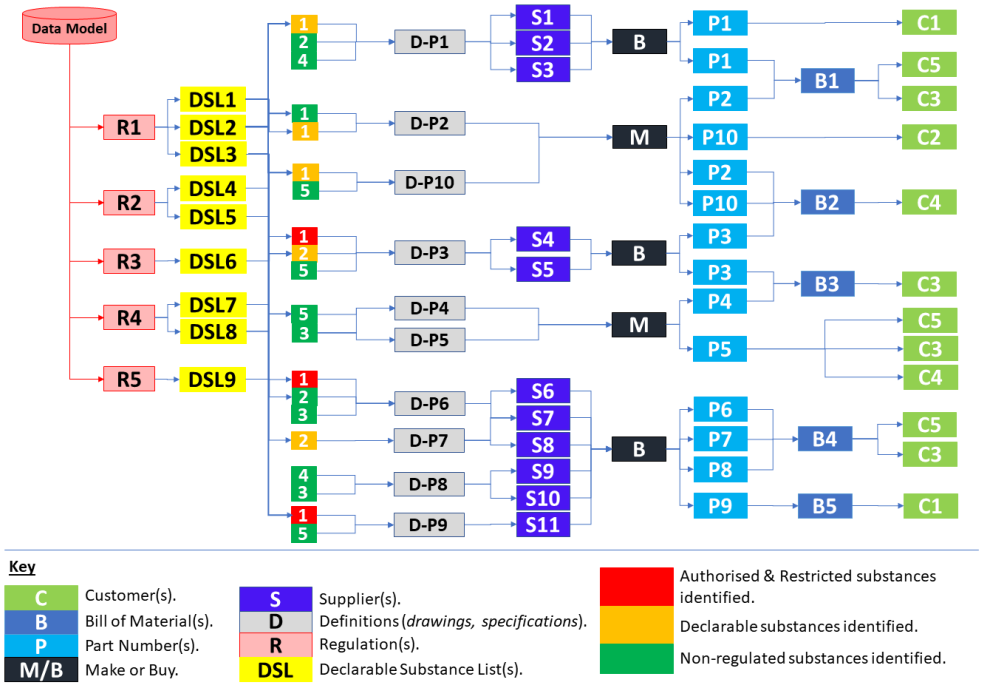


Figure 6-14: Data Modelling Logic

6.4.4 Data Load Templates: Identifying Sources of Data

6.4.4.1 Supplier Pre-Engagement Activities

This section describes activities to assess supplier capabilities to perform compliance reporting and setting appropriate contract terms and initiate any remedial actions. The need for this section arose from on-going engagement activities with AD organisations, including AD organisations engaged with during the Delphi Studies. When key issues were being discussed, the following suggested activities, conducted prior to formal supplier engagement are seen as being critical to ensure desired supply chain data responses from the supply chain. The suggested supplier pre-engagement activities provide: (1) standardised buyer-supplier contractual language, that enables a buying organisation to dynamically adjust reportable chemical regulations, without needing to generate new contracts as new chemical regulations arise, as well as; (2) ensuring appropriate penalties for non-compliant reporting from a supplier being utilised to offset any costs of having obtain substance related data via testing of AD articles.

6.4.4.2 Suggested Supplier Contractual Language Example

Issues identified against existing AD buyer-supplier contracts are:

- Clarity over the expected regulations and types of reporting required;

- The regulations are listed within the contracts as specific name and dated versions, which may result in resistance to reporting from supplier, in instances where a given chemical regulation is updated and reporting obligations increase;
- The frequency of reporting required;
- Any specific reporting standards and formats the supplier is expected to adhere to;
- Identification of appropriate regulatory contacts within the supplier organisation, that can readily respond to any regulatory compliance requests from the buyer organisation. A common theme is where a buyer organisation requests the data from the supplier sales contact, which is not the correct individual to respond correctly to the request;
- Little consideration is defined in such contracts for non-reporting, penalty clauses need to be established to ensure the supplier understands that is no data is provisioned, this is considered a potential business continuity risk to the buyer organisation that needs the information maintain their compliance reporting, into markets where the reporting is mandatory.

The following criteria have been discussed with several AD organisations and established as being critical to ensuring suppliers respond correctly against any material declaration requests:

- Use of following term(s):
    a. Supplier agrees to adhere to the provisioning data against the Buyer organisation list of reportable regulations, reviewing the list on at least a three-month cadence.
        i. Buyer organisation maintains a dynamic list of regulations, updating as new regulations are created or existing chemical regulations are updated. This avoids the need to renegotiate contractual obligations in the event of future changes.
        ii. Supplier agrees to review the list, and report against the chemical regulations stated, in the desired reporting formats at a defined reporting frequency, where regulations such as EU REACH update reportable substance lists on a 6-month cycle
    b. Supplier defines regulatory compliance contact details to enable the Buyer to request regulatory compliance information as desired.
    c. Supplier agrees to a penalty clause stipulating initial escalation paths, review of supplier adherence, remedial actions, failing which supplier must accept the costs of performing material testing such as independent XRF type testing, other

non-destructive material testing, to identify the chemical substances present on the supplier AD Article(s).

6.4.4.3 Data Collection

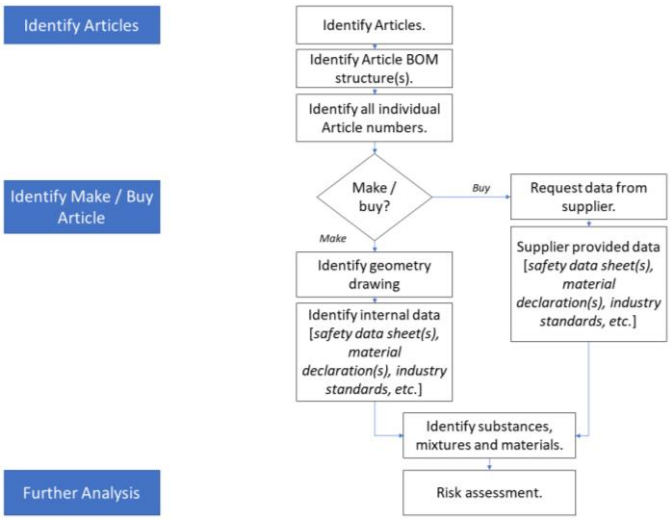


Figure 6-15: Envisaged Data Collection Activities

The process for collecting information relating to chemical substances, mixtures, and materials to support the further analysis activities conducted in the conceptual framework is shown in Figure [6-15], in terms of: (1) a make part is considered to be an article that is internally manufactured by an AD organisation, or; (2) a buy part is considered to article to be externally manufactured and sourced from the supply chain. Based on (1) and (2) the process of source data collection will be based on data from internal product definitions or from the collation of supply chain reporting information.

6.4.4.4 Supply Chain Data Collection Activities

Having identified buy type articles and suppliers, the next step in the process, is performing the supply chain data collection activities. The following tasks assume that an AD organisation has undertaken some form of supplier pre-engagement activity to assess the supplier's capability and agreement to provision data in relation to chemical substances on provisioned AD articles.

6.4.4.4.1 Initial Supplier Declaration Requests

The *SupplierDeclaration* data load template is populated with supplier ID data from *SupplierList* data load template, which records supplier location details, additionally noting GDPR related data in the *SupplierGDPR* data load template. The assumption is that the AD organisation may choose to request supply chain material declarations reporting using: (1)

existing supplier material declaration templates developed internally; (2) data exchange templates based on IPC-1752 or IPC-1754 (author developed) data elements; (3) industry standard supply chain reporting template IAEG AD Substance Reporting Tool, which the author helped to develop, or; (4) an XML or MS-Excel sheet based on the DetailedDeclaration template. The *DetailedDeclaration* data load template records the detailed supplier material declaration information. Data from (1), (2), or (3) can be extracted into the same fields as defined in the *DetailedDeclaration* load template.

6.4.4.4.2 Initiating Positive Supplier Material Declaration Requests

Where suppliers have identified regulated chemicals as being on supplied articles, the *PositiveDeclaration* data load template can be utilised to request supporting information from a supplier in relation to the identified chemical substance, aiming to identify additional information such as supplier awareness and strategy to potentially substitute the hazardous chemical with a non-hazardous chemical. Prior to sending the *PositiveDeclaration* data load template, the AD organisation will need to omit columns B, C, D, E, F, G, H, and then splitting out the positive declaration requests by supplier.

6.5 [RQ4] How should the framework be implemented within a typical AD organisation to identify any potential impacts posed by chemical regulations?

This question addresses the initial DEPLOY and MAINTAIN phase activities. The activities are identified as: Review using system output reporting as shown in section 6.5.1. Review using the system output reporting to assess the impact of chemical regulations, as shown in section 6.5.2. Review application of IEC 63000 risk methodology (dashboard application only), as shown in section 6.5.3. Review the review boards as shown in section 6.5.4. Review regulatiory compliance readiness level (supplier assessment) as shown in section 6.5.5. Review the external stakeholder engagement section as shown in section 6.5.6. Review the data maintenance activities as shown in section 6.5.7. The expectation is that these tasks should take in the region of 3 to 9 months to complete.

6.5.1 System Output Reports

System output reporting based on the application UI structure providing a guide for the application to launch applicable reports run against the data imported into the application

via the MS-Excel based data load template files. Detailed examples of SQL statements used to generate the applicable system output reporting are shown in Appendix [20].

6.5.1.1 Available System Outputs Reports

System output reports are categorised in terms of (i) core, and (ii) extended system reporting. Table [6-9] defines a summary of available system output reports:

Table 6-9: Available System Output Reports

Report type	Report name	Report description	Where found in application
Core.	Search by a list.	Select a reportable substance list to return all applicable records.	• HSE Function → Master Chemical Inventory List. • HSE Function → Substance Analysis. • Regulatory Compliance → Article Definitions. • Regulatory Compliance Function Menu → Supplier Declarations.
	Search by trade / product name.	Search records against trade or product names to return all applicable records.	• HSE Function → Master Chemical Inventory List. • HSE Function → Substance Analysis. • Materials Function → Substance Analysis.
	Search by substance name.	Search records against substance names to return all applicable records.	• HSE Function → Master Chemical Inventory List. • HSE Function → Safe Use Guidance. • HSE Function → Substance Analysis. • Materials Function → Substance Analysis. • Regulatory Compliance → Article Definitions. • Regulatory Compliance Function Menu → Supplier Declarations.
	Search by CAS number.	Search records against CAS number to return all applicable records.	• HSE Function → Master Chemical Inventory List. • HSE Function → Safe Use Guidance. • HSE Function → Substance Analysis. • Materials Function → Substance Analysis. • Regulatory Compliance → Article Definitions. • Regulatory Compliance Function Menu → Supplier Declarations.
	Search by EC number.	Search records against EC number to return all applicable records.	• HSE Function → Master Chemical Inventory List. • HSE Function → Safe Use Guidance. • HSE Function → Substance Analysis. • Materials Function → Substance Analysis. • Regulatory Compliance → Article Definitions. • Regulatory Compliance Function Menu → Supplier Declarations.
Extended.	Search status values.	Search records against a specific status value to return all applicable records.	• HSE Function Menu → Safe Use Guidance. • HSE Function Menu → Substance Analysis. • Materials Function Menu → Mixture Analysis. • Materials Function Menu → Material Analysis. • Materials Function Menu → Substance Analysis. • Design Function Menu. • Engineering Function Menu. • Purchasing Function Menu. • Sales Function Menu. • Manufacturing Function Menu. • Stores Function Menu. • Accounting Function Menu.

Report type	Report name	Report description	Where found in application
			• Regulatory Compliance Function Menu → Supplier Declarations. • Regulatory Compliance Function Menu → Positive Declarations. • Regulatory Compliance Function Menu → ECHA SCIP Database Reporting Analysis. • Regulatory Compliance Function Menu → Component 1 Ton Analysis. • Regulatory Compliance Function Menu → Part Number 1 Ton Analysis. • Regulatory Compliance Function Menu → Assembly 1 Ton Analysis. • Regulatory Compliance Function Menu → Customer Declarations.
	Table of records.	Display all records in table.	• Materials Function Menu → Mixture Analysis. • Materials Function Menu → Material Analysis. • Purchasing Function Menu. • Sales Function Menu. • Quality Function Menu. • Stores Function Menu. • Airworthiness Function Menu. • MRO Function Menu. • Regulatory Compliance Function Menu → Positive Declarations. • Regulatory Compliance Function Menu → Customer Declarations. • Tech Pubs Function Menu. • View Change Log.

The system output reporting generated by the application will enable AD organisations to identify substances which require internal review and action(s) to be undertaken as part of feedback mechanisms to support internal decision support systems.

6.5.2 Using System Output Reporting to Assess the Impact of Chemical Regulations

Following the generation of system output reports, the following sections cover obligations AD organisations should consider as follow-on actions.

6.5.2.1 Design Intent

The original design intention of conceptual framework design was to identify: (1) AD stakeholders, internal and external; (2) the flow of substances, mixtures, materials, and articles across the AD supply chain; (3) chemical regulations and applicable chemical substance lists which must be adhered to, in terms of identifying obligations for AD article manufacturers; (4) the required data elements and sources of data from (1) and (2); identify a method of collating the data in the form of data load templates; (5) ingesting the data fields

into data model to support system output reporting to be generated which identifies possible business risks, and actions as shown in Figure [6-16].

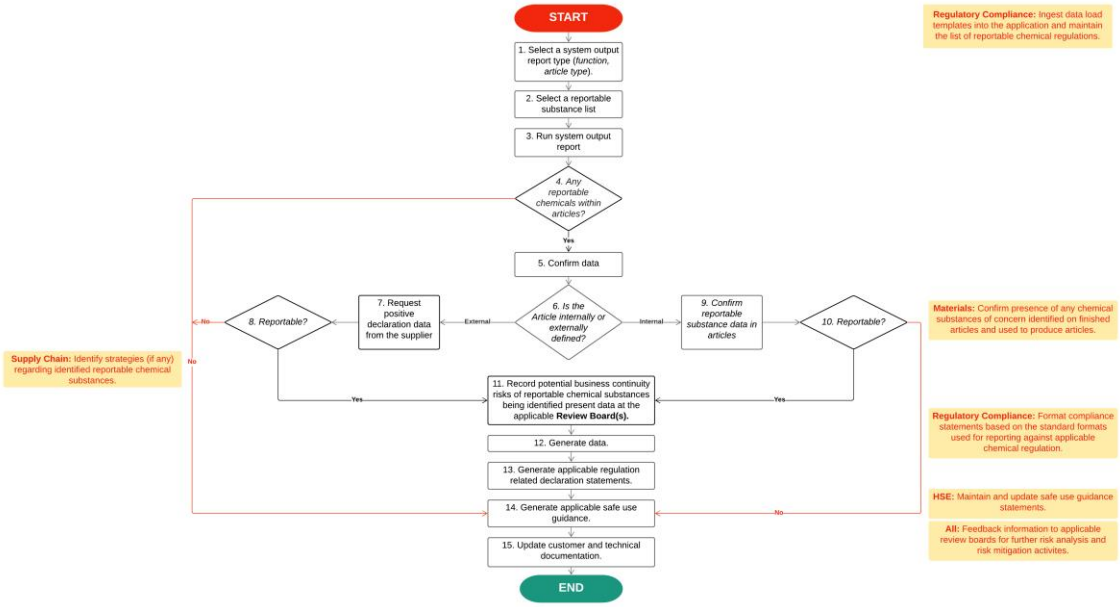


Figure 6-16: Identifying the Impacts of Chemical Regulations

A deliberate design intent chosen by the author was to avoid the use of traditional relational database modelling techniques to define data field types, generation of custom objects and classes, which would have resulted in a highly configured database, that would be difficult to sustain and expand over time. The approach adopted in this detailed design section, allows for new data fields to be added to a given data load template, which can subsequently be populated with data, ingested into the application and any system output reports may be adjusted to allow for reporting of any additional data fields.

6.5.2.2 Identify if Applicable Regulator Notifications Required

Several chemical regulations assume a nominal 1 tonne per annum usage of a chemical substance, consumed: (1) on its own; (2) within a mixture or material; (3) rolled up into a finished article. The applicable substance mass calculations are shown in Appendix [19], where the applicable data load template files contained the MS-Excel calculation formula. Within the database application, specific system output reports support the 1 tonne per annum threshold analysis, which can be found under: Database Application → Regulatory Compliance Function Menu → Additional Regulation Specific Analysis → 1 Ton Threshold Reporting Analysis.

6.5.2.3 Identify Chemical Substances and Register Uses with Manufacturers

Figure [6-17] describes the process of looking at internal definitions, from step 7, to derive the current state chemical substances, mixtures and materials being used to produce articles, from where, a proactive step identified by the author, is to contact the manufacturers of the chemical substances, mixtures and materials and register the AD organisations use of a given chemical substance, mixture, or material.

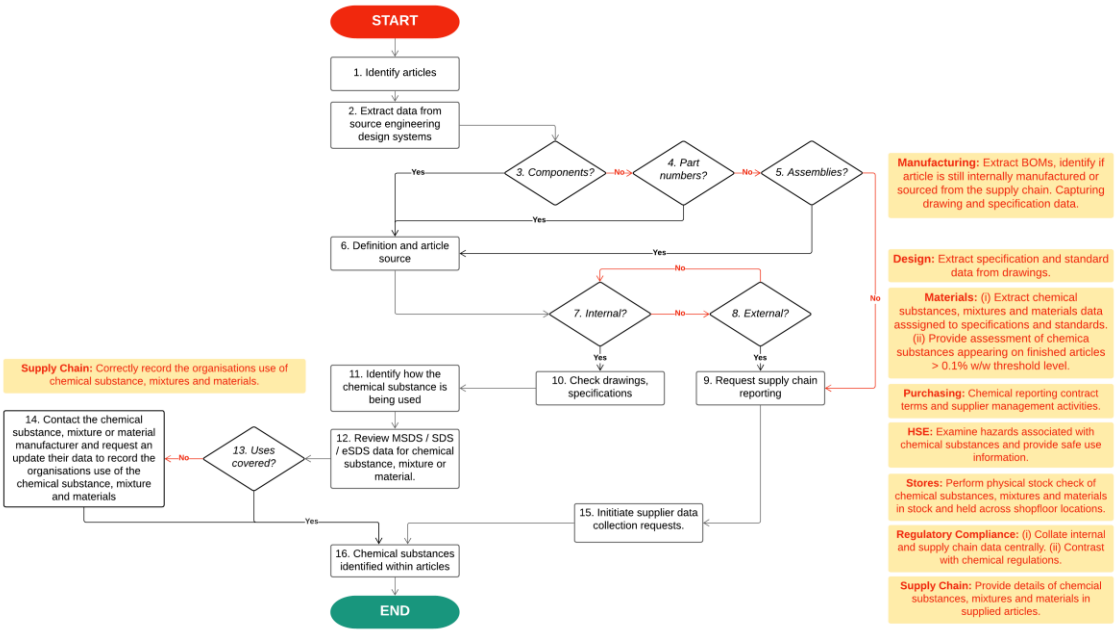


Figure 6-17: Identifying Chemical Substances and Registering Uses with Manufacturers

The criticality of this task cannot be understated:

1. In collecting internal and supply chain data on the use of chemical substances used on their own or within mixture or materials, the AD organisation can identify known uses of a chemical and where used.
2. Correlating the identified chemical substance names against any chemical regulation(s) list(s) of chemicals of concern.
3. Correlating the identified use of a chemical against any SDS / MSDS type system data, and / or request AD organisation specific uses of a chemical substance is identified with the material, mixture, substance manufacturers. The formulators use this type of registered use data supplied by industry, when making their regulation specific notifications. Without such data, in the event of a chemical substance moving from an initial chemical watch list to a more controlled substance list, if the AD organisation use of a chemical substance is not on an official authorised use, defined on the more controlled substance list, then the AD organisation use of a

chemical substance may become restricted, requiring a significant data collection and cost of requesting any retrospective approvals from a regulator.

4. Suppliers via training activities should be encouraged to follow the same process and register their use of chemical substances, mixtures, and materials with their applicable manufacturers.

6.5.2.4 Generate Safe Use Guidance Statements

As new chemical substances are identified the applicable safe use guidance needs to be generated in the *SafeUseGuidance* data load template and updated by the HSE function, from which updates to existing technical publications can be made via Technical Publications function, who will be referencing the SafeUseGuidance *TechnicalPublications* data load template, cascading the safe use guidance within all applicable technical publication locations referencing the applicable AD Article number.

6.5.2.5 Generate Customer Declarations

Figure [6-18] defines a high-level process where the regulatory compliance function utilises data ingested within an application to .generate customer declarations. Table [6-10] identifies the detailed steps that need to be undertaken to generate customer declarations, which an AD organisation would provide to its downstream (customer) users. Within the Regulatory Compliance Function of the Database application, several system output reports support the process of generating customer declarations.

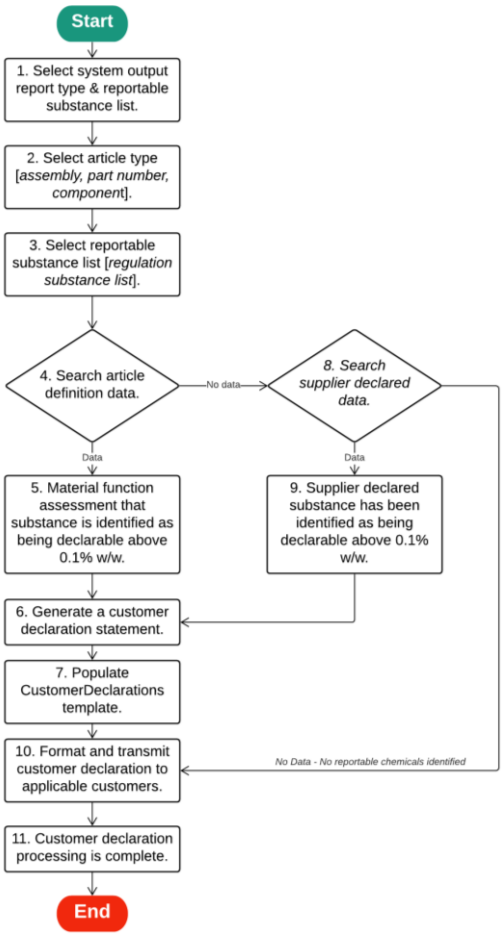


Figure 6-18: High-Level Overview of Customer Declaration Generation Process

Table 6-10: Tasks to be Undertaken to Generate Customer Declarations

Task	**Data load template name**	**Tasks to be undertaken**
Review internal definitions.	N/A.	• Application → Regulatory Compliance Function Menu → Review Definitions → Select [Reportable Substance] in the left-hand pane and then run the query against: ○ Search [*Component / Part Number / Assembly*] Drawing definitions by CAS number: ▪ This will return data for identified chemical substances defined without a specification number against an article. ○ Search [*Component / Part Number / Assembly*] Specifications definitions by CAS number: ▪ This will return data for identified chemical substances defined against a material / process specification number against an article. • Extract data records for the article types where the **MaterialsAssessment** field value is defined as **Substance is declarable above 0.1% w/w.**
Review supplier declared information.	N/A.	• Application → Regulatory Compliance Function Menu → Supplier Declarations → Select [Reportable Substance] in the right-hand pane → Below the list of reportable substances, select **Cross-Reference Reportable List Against Supplier Declaration Data User CAS Number.** ○ Extract data records for all returned articles with the details of the chemicals of concern identified from supplier declarations.

Task	Data load template name	Tasks to be undertaken
Review supplier positive declaration information.	N/A.	• Application → Regulatory Compliance Function Menu → Positive Supplier Declarations → In the right-hand pane select **Positive Declaration Status** of **Positive Declaration Completed** ○ Extract data records for all returned articles with the details of the chemicals of concern identified from supplier positive declarations.
Ensure correct safe use guidance in relation to the chemical substance exists.	SafeUseGuidance.	• Application → Health, Safety and Environment Function Menu → Safe Use Guidance → In the left-hand pane select **View Defined Safe Use Guidance Statements.** ○ Extract safe use statements that have been defined in relation to a given chemical substance (as identified in the earlier reports). ○ Where safe use statements for chemical regulations do not exist → Connect with HSE function to ensure statements are generated. ▪ When new safe use statements are generated, the HSE function will update the SafeUseGuidance data load template file.
Generate customer declarations.	CustomerDeclaration.	• Using the above data, generate customer declarations based on: ○ Internally defined articles having the **MaterialsAssessment** value set as **Substance is declarable above 0.1% w/w**. ○ Supplier declared substances in articles. ○ HSE function has generated the applicable safe use statements to be provided with the customer declarations to downstream customers of the AD organisation, referencing data shown in the SalesForwardLoad data load template.
Update technical documentation.	TechnicalPublications.	• Following the creation of a customer declaration, the technical publication's function needs to be informed, to ensure declarable data and safe use data is provisioned correctly in any applicable technical document(s) relating to the article sold by the AD organisation.

6.5.2.6 Update Technical Publications

Updates to existing technical publications can be made via Technical Publications function, who will be referencing the *SafeUseGuidance* data load template within the *TechnicalPublications* data load template, cascading the substance related safe use guidance within all applicable technical publication locations referencing the applicable AD Article number.

6.5.3 Application of IEC 63000 Risk Methodology *(Dashboard Application Only)*

IEC 63000 (BSi, 2021) defines a basic risk assessment methodology for assessing technical documentation in the context of electrical and electronic products. IEC 63000 was originally developed in the context of the EU RoHS regulations (EU, 2003; EC, 2011). Under IEC 63000, the prescribed risk methodology is shown in Figure [6-19].

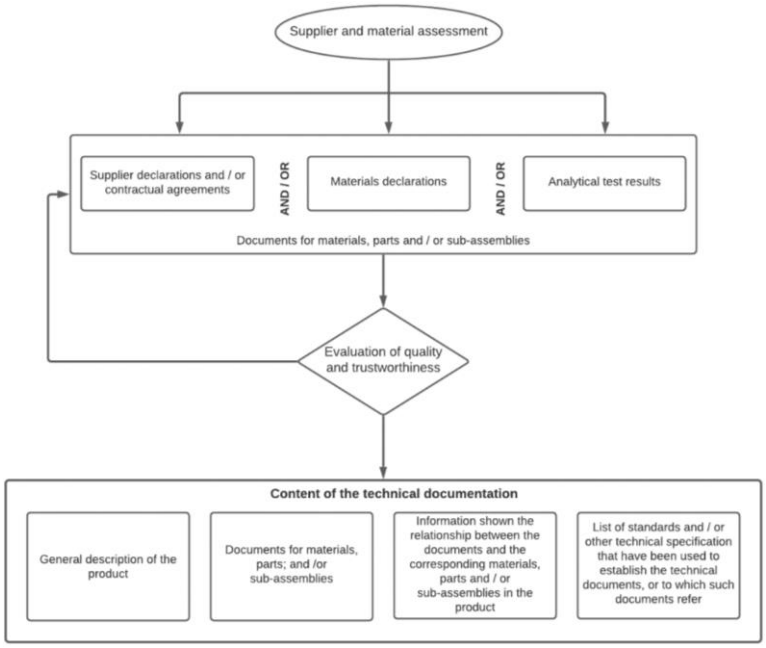


Figure 6-19: IEC 63000 Risk Assessment Methodology, BSi (2021).

6.5.3.1 Author Adapted IEC63000 Type Analysis *(Dashboard Application)*

In the context of this research study, the author developed several additional logical indexes, instead of the default chemical list to supplier indexes contained within IEC 63000 (BSi, 2021) to enable a risk assessment of suppliers to be undertaken, based on a chemical of concern substance being identified against a given article, as shown in Figure [6-20].

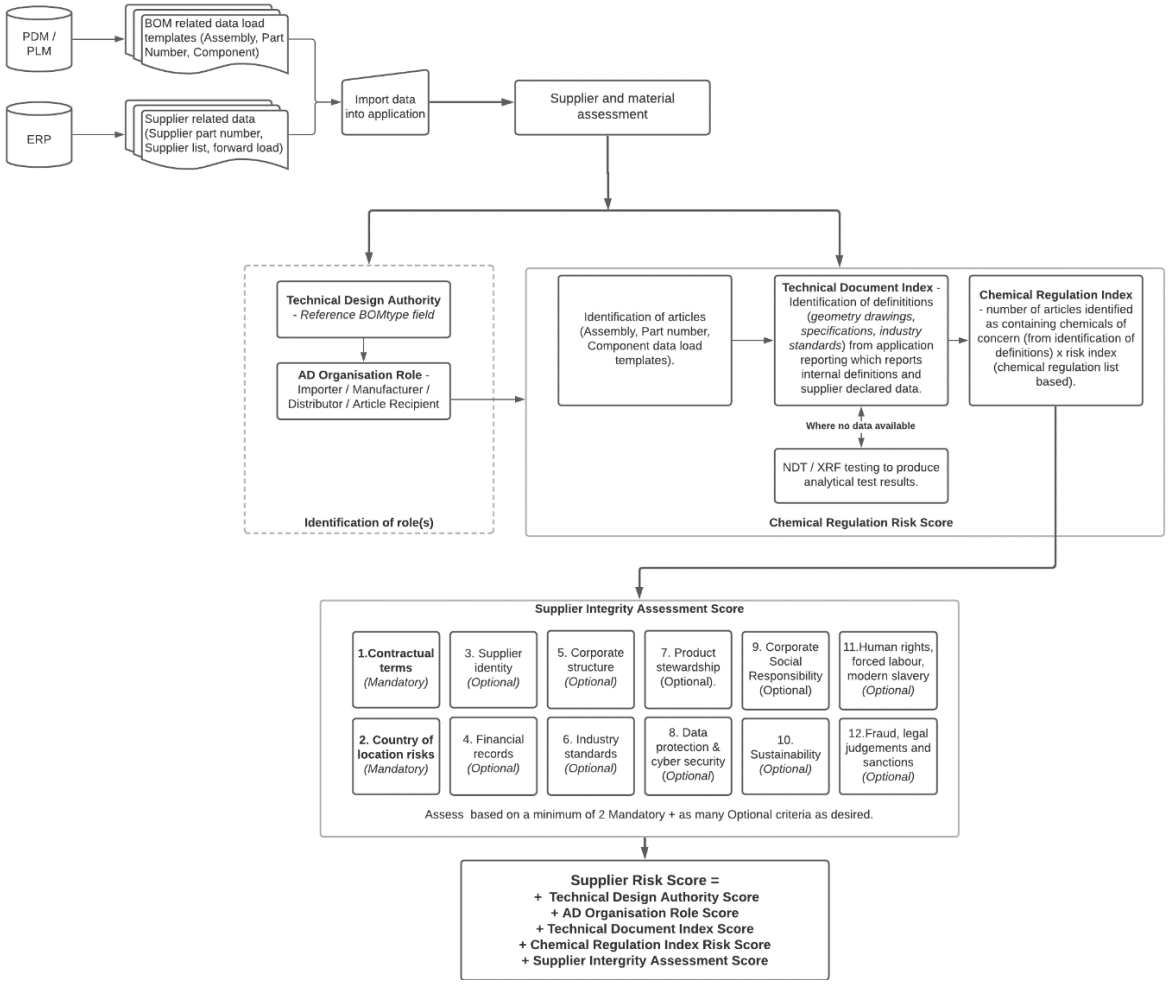


Figure 6-20: Author defined supplier risk assessment methodology adapted from BSi (2021).

The detailed processing for author adapted IEC6300 risk assessment methodology is shown in Appendix [21].

6.5.3.2 Updated Data Model [Final]

As a result of implementing the risk analysis, additional data load templates were utilised requiring an extension to the data model, the additional data load templates are presented in blue text, in the final data model is presented in Figure [6-21].

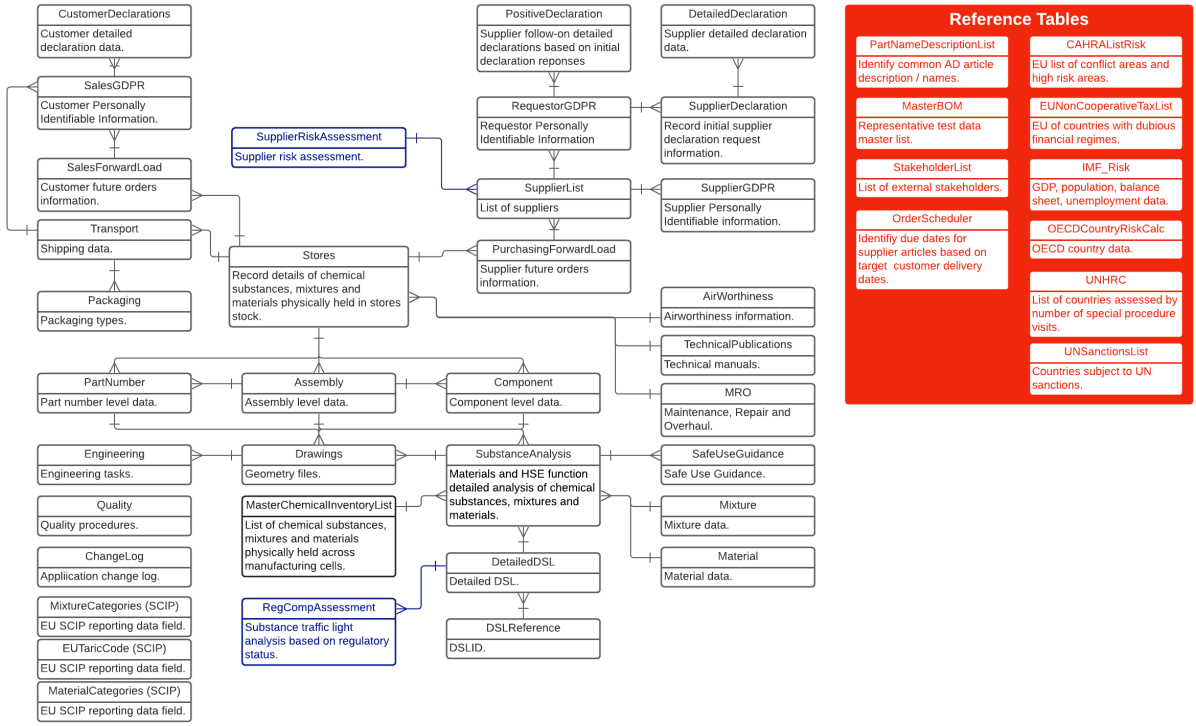


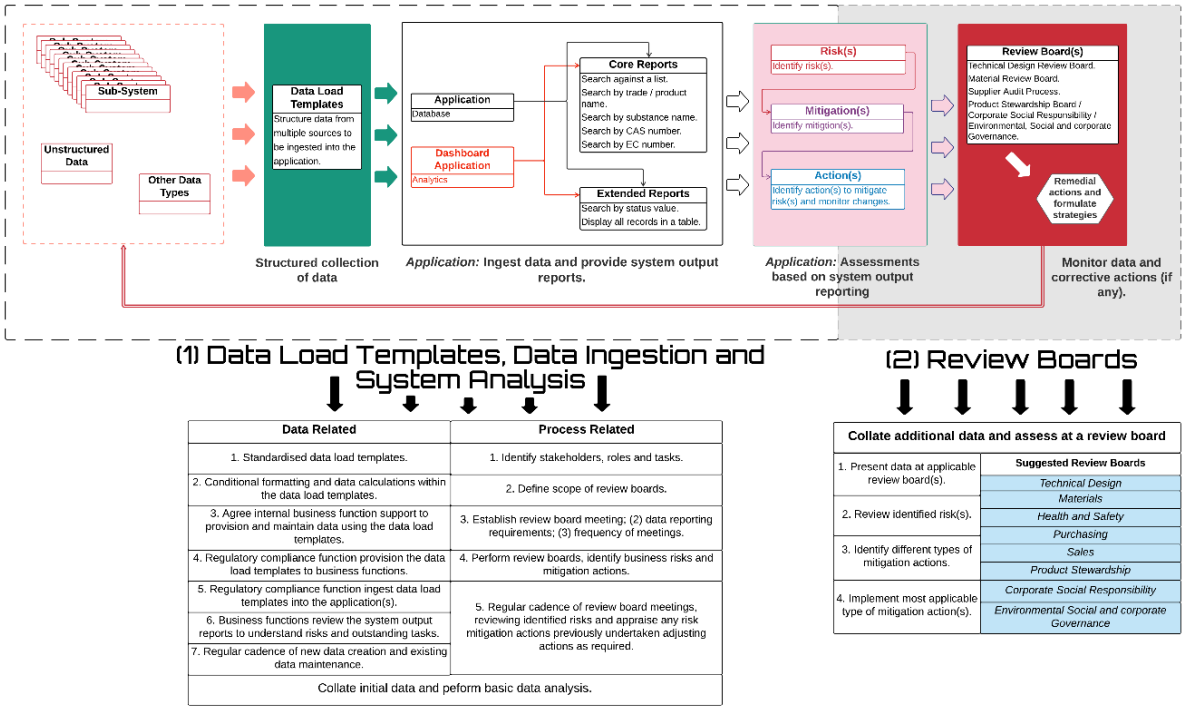
Figure 6-21: Final Data Model

6.5.4 Review Boards

This section describes the establishment of review boards to review data generated by the framework, assessing risks, and defining applicable mitigation actions.

6.5.4.1 Review Board Assessment Logic

Figure [6-22] presents a high-level view of using standard and extended data analysis being conducted to feed into the control of identified risks by the applicable review board(s).



(1) Data Load Templates, Data Ingestion and System Analysis

Data Related	Process Related
1. Standardised data load templates.	1. Identify stakeholders, roles and tasks.
2. Conditional formatting and data calculations within the data load templates.	2. Define scope of review boards.
3. Agree internal business function support to provision and maintain data using the data load templates.	3. Establish review board meeting: (2) data reporting requirements; (3) frequency of meetings.
4. Regulatory compliance function provision the data load templates to business functions.	4. Perform review boards, identify business risks and mitigation actions.
5. Regulatory compliance function ingest data load templates into the application(s).	5. Regular cadence of review board meetings, reviewing identified risks and appraise any risk mitigation actions previously undertaken adjusting actions as required.
6. Business functions review the system output reports to understand risks and outstanding tasks.	
7. Regular cadence of new data creation and existing data maintenance.	
Collate initial data and peform basic data analysis.	

(2) Review Boards

Collate additional data and assess at a review board	
1. Present data at applicable review board(s).	Suggested Review Boards
2. Review identified risk(s).	*Technical Design*
3. Identify different types of mitigation actions.	*Materials*
4. Implement most applicable type of mitigation action(s).	*Health and Safety*
	Purchasing
	Sales
	Product Stewardship
	Corporate Social Responsibility
	Environmental Social and corporate Governance

Figure 6-22: High-Level Overview of System Output Reporting Feeding into Review Board Assessments

6.5.4.2 Establishing Review Boards

Table [6-11] adapted from Takhar and Liyanage, 2019b, which was originally generated to discuss embedding a product stewardship culture, within the remit of this research, this table has been updated to reflect the same approach to implementing suggested review boards within an AD organisation.

Table 6-11: Tasks to Embed Review Boards

#	Task	Task details
1.	Identify internal actors.	• All relevant stakeholders within an organisation need to be engaged. • Engage with all internal stakeholders such as design, purchasing, manufacture, quality, sales, etc.
2.	Agree actors.	• Clearly identify who will be part of the review board panel. • Actors need to be committed to attend, review board meetings, and support the process.
3.	Establish initial objectives.	• Review applicable review board literature. • Brainstorm and set high-level initial goals.
4.	Embed and engage to create a product stewardship culture.	• Embed review boards in as many business decisions making processes as possible. • This will require the actors supporting the review board panel process to engage with all related functions explaining the new review board panel culture being adopted.

5.	Define more detailed objectives.	• Develop a more thorough set of objectives.
		• This will include setting clear targets relating to:
		  ○ The use of regulated chemicals with a potential shift towards the use of non-toxic chemicals;
		  ○ Developing products which are more sustainable (materials and resources) and can feed into the circular economy.
		• These objectives should result in clear aims.

6.	Gap analysis.	• Analyse the current state organisation.

#	Task	Task details
		• Assume objectives in step (5) represent the future desired state for the organisation. • Identify gaps which exist today, which prevent the objectives from being completed.
7.	Roadmap.	• Develop a roadmap of activities.
8.	Action plan.	• Define action plan that defines required tasks and task owners.
9.	Identify external stakeholders.	• Identify key external stakeholders to your organisation who will be impacted by changes required by the action plan. • Engage with stakeholders to provide insights of the proposed changes. • Understand impacts of changes on external stakeholders. • Review initial feedback, adjust the action plan as required.
10.	Promote openness.	• Develop a culture for the review board which encourages stakeholders to feel that their views matter and are responded to, within the review board panel.
11.	Establish gated reviews.	• Establish gated review process for key business processing stages. • Establish key milestones for different functional areas within an organisation to engage with the review board panel for advice and approval review(s).
12.	Enforce gated reviews.	• Ensure all relevant business decisions are reviewed by the applicable review board panel. • This should cover reviewing existing products as well as reviewing new products as the move from design, manufacture, testing prior to being placed onto a marketplace.
13.	Continuous improvements.	• Regularly monitor the changes reviewed by the review board panel. • Adjust decisions and actions to align with chemical regulation, sustainability, and circular economy targets.

Source: Takhar and Liyanage, 2019b.

6.5.4.3 Suggested Review Boards

To correctly assess the impacts of identified risks appropriate internal review boards should be established. Table [6-12] depicts suggested review boards, to implement, where the data generated from the from the application can be utilised to make additional informed decision making, based on identified risks. Where AD organisations have established review boards, then it is assumed the applicable existing review boards may be expanded to include a review of the data generated by this research study.

Table 6-12: Suggested Review Boards

#	Review board name	Responsibilities	Key activities	Internal actors	External actors	Data templates that support analysis	Example mitigation action(s)
1	Technical design.	Review article configuration management activities.	Review internal and external change requests, drawings, specifications, manufacturing, testing and inspection tasks.	Materials; Design; Engineering; HSE; Quality; Regulatory compliance.	Suppliers; Customer requirements; Airworthiness approval bodies.	Assembly; PartNumber; Component; Drawing; SubstanceAnalysis; Engineering; RegCompAssessment.	Review article design, manufacturing, testing and safety data. Assess the impact(s) of chemical regulations in terms of potential article redesign activities.
2	Materials.	Chemical substances, mixtures and materials defined against specification. Specifications are used by the design function, assigned to applicable engineering drawings.	Review chemical substances, mixtures and materials defined against specifications. Approve new specifications and updates to existing specifications.	Materials; Design; Engineering; HSE; Quality; Regulatory compliance.	Suppliers (substances, mixtures, materials, components, part numbers and assemblies).	Material; Mixture; SubstanceAnalysis; RegCompAssessment.	Identification of chemical substances, mixtures and materials defined against specifications. Investigation of alternative chemicals where specifications define restricted substances. This may trigger article redesign and approval tasks.
3	HSE.	Ensure the health and safety of employees, consumers, and society, whilst protecting the environment.	Review storage, handling, disposal documentation. Review manufacturing tasks for any associated risks. Review any resultant occupational exposure data.	HSE; Materials; Engineering; Quality; Regulatory compliance.	National and international regulators. Airworthiness approval bodies (*EASA*, *CAA*, *etc*.)	ChemicalSubstanceInventory; SafeUseGuidance; SubstanceAnalysis.	Assessment of procedures to handle chemical substances, mixtures, and materials. Perform applicable assessments in terms of storing, handling, using and disposal of chemical substances. This will include a review of any existing labelling, packaging and safe use instructions. Update internal documentation. Update documentation provided to downstream users.

#	Review board name	Responsibilities	Key activities	Internal actors	External actors	Data templates that support analysis	Example mitigation action(s)
4	Purchasing.	Review supplier engagement activities and strategies.	Establish contract terms, KPIs, audit criteria and outline remedial action(s) for suppliers in terms of chemical substance reporting.	Purchasing; Stores; Quality; Regulatory compliance.	Suppliers.	PurchasingForwardLoad; Stores; Drawing; SupplierGDPR; SupplierList; SupplierDeclaration; PositiveDeclaration; Engineering. SupplierRiskAssessment.	Determine the chemical regulations in scope of suppliers to report against. Define format of how the data is to be reported by suppliers and any specific validation needed. Define frequency and occurrence of the reporting. Define supplier training requirements. Undertake regular supplier audits to ensure supplier performance meets defined KPIs.
5	Sales.	Assessing article sales, where sold, with associated sale data.	Review customer sales orders, unique configuration requirements, with any customer specific reporting requirements for chemical substance reporting.	Sales; Design; Engineering; Regulatory compliance; Quality.	Customers. Airworthiness approval bodies (*EASA, CAA, etc.*)	SalesGDPR; SalesForwardLoad; SafeUseGuidance; CustomerDeclaration; TechnicalPublications; Packaging; Transport.	Identification articles sold to customers. This results in the identification of downstream users, to be referenced to any chemical regulation reporting obligations.
6	Product Stewardship Board (PSB).	Examine the health, safety, environmental and social risks of an article across its entire lifespan.	Review chemicals contained in articles. Ensure articles undergo appropriate testing, inspection and meet safety requirements. Identify the amounts of energy and waste generated by the organisation.	HSE; Materials; Design; Engineering; Purchasing; Sales; Stores; Accounting; Airworthiness; MRO; Technical Publications;	National and international regulators. UN SDGs (UN SDG, 2020). Environmental and social standards for example GRI (GRI, 2020).	SafeUseGuidance; CustomerDeclaration; TechnicalPublications; Engineering; DSLReference; DetailedDSL. SupplierRiskAssessment.	Identify chemicals of concern identified from chemical regulations. Ensure appropriate safe use guidance and declarations are generated. Identify critical raw materials being consumed, to develop waste and end-of-life recycling strategies. Develop mechanisms to receipt sold articles at their end of life cycle stage.

#	Review board name	Responsibilities	Key activities	Internal actors	External actors	Data templates that support analysis	Example mitigation action(s)
				Regulatory Compliance; Quality.			Using Life Cycle Assessment methods reduce carbon footprint of the organisation such as alternative energy sources, recycling of waste articles.
7	Corporate Social Responsibility (CSR).	Responsible for alignment of the organisations business purpose (*to generate profits*) towards its social and environmental actions.	As above. Invest in projects that bring about positive impacts to the local and national communities.				As above. Increased investigation of UN SDGs (UN SDG, 2020). Developing goals for the organisation (where applicable).
8	Environmental, Social, and corporate Governance (ESG).	Future state alignment of organisational activities and reporting data.	As above. Increased monitoring, control, and reporting from CSR objectives.				As above. Track emerging reporting requirements. Implement systems to monitor CSR investments, collecting applicable data and reporting in company reports (non-financial section).

6.5.5 Regulatory Compliance Readiness Level (Supplier Assessment)

The conceptual Regulatory Compliance Readiness Level (RCRL) was created as a guide for AD organisations to assess the capability of a supplier in terms of regulatory compliance capability to support reporting against chemical regulations. Figure [6-23] presents the RCRL, suppliers would be assessed in terms of where they fall under the applicable topic areas of: (1) being a technical design authority; (2) regulatory awareness; (3) data cleanliness; (4) the suppliers own contractual terms with its suppliers; (5) the suppliers supply chain data collection activities; (6) data modelling / analysis, and; (7) data reporting. The lower the RCRL level assigned to a supplier means the likelihood of the supplier being able to respond to the AD organisations, supply chain data reporting requests for chemical substance related data.

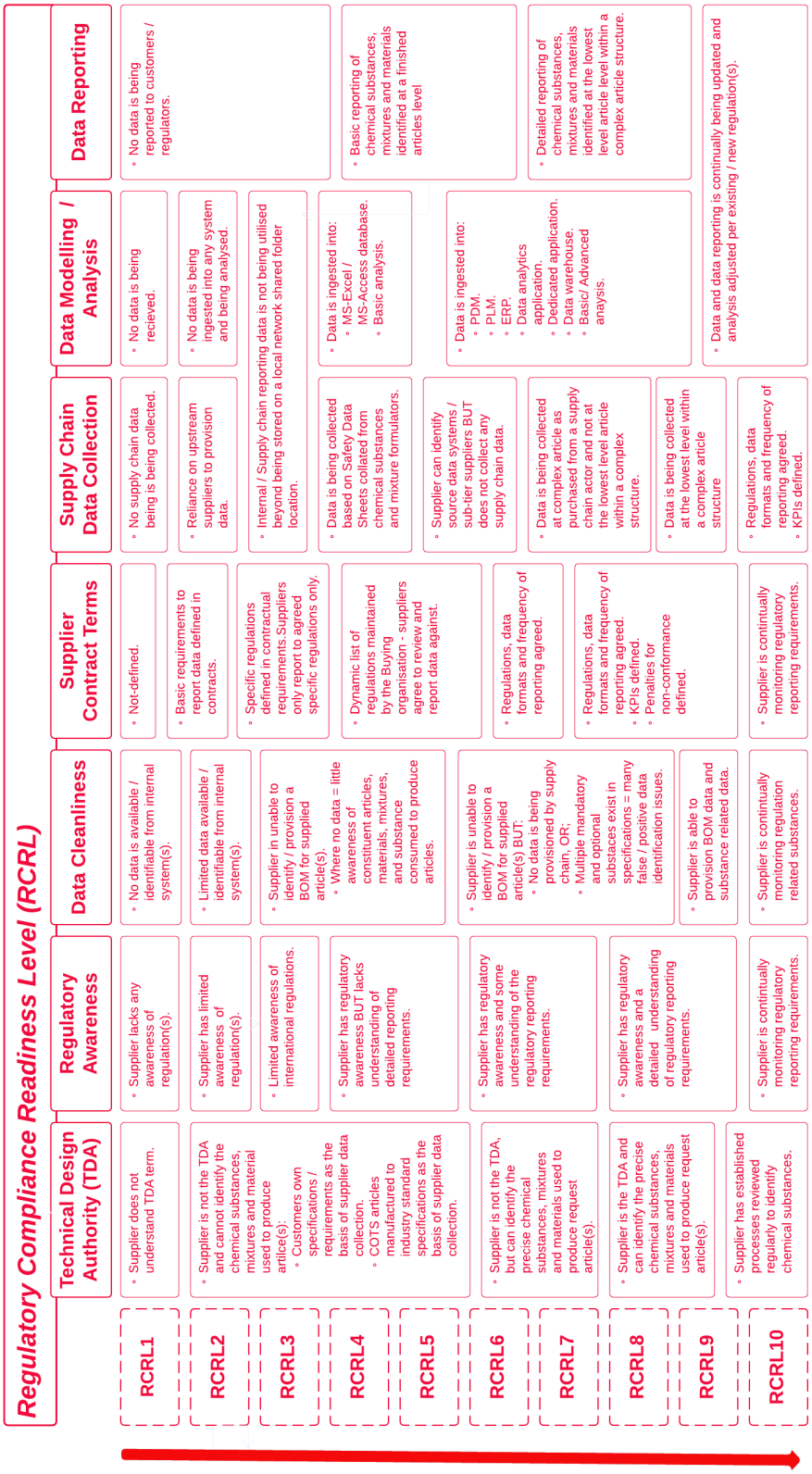


Figure 6-23: Conceptual Regulatory Compliance Readiness Level Assessment Scale

6.5.6 External Stakeholder Engagement

When chemical substances are being considered for further regulatory control measures, beyond an initial watch list with simple downstream user communications, then, AD

organisations need to act by engaging with a wider range of external actors, to develop strategic positions to inform regulators, during public consultations for further control measures. Figure [6-24] depicts a phased approach to developing a strategic direction.

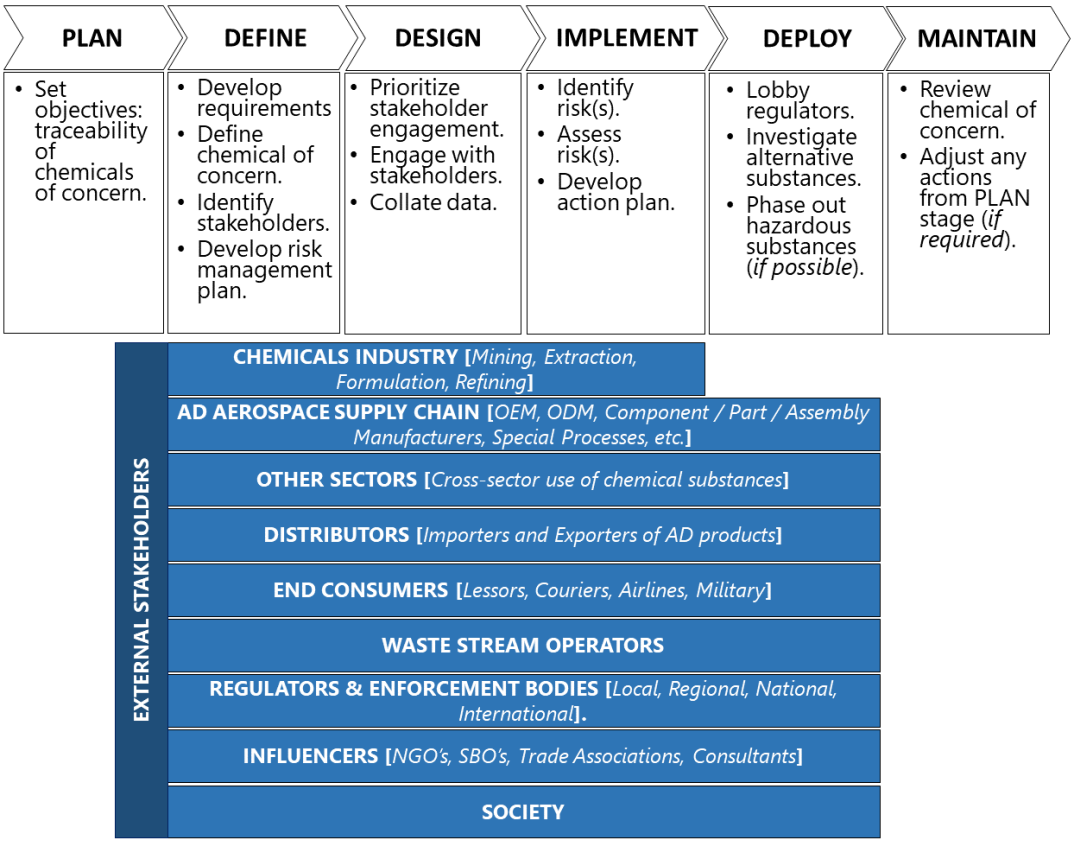


Figure 6-24: Developing a strategic position with external stakeholders
Adapted from: Porter, 1980; CMMI Wiki, 2019; CMMI Institute, 2020

Logically an AD organisation may generate based on a given chemical substance, a list of applicable external actors as shown in bold in Figure [6-24] The author has generated reference table StakeholderList as an example of a list of external to AD stakeholders. Once identified, the AD organisation will need to connect with applicable external stakeholders to formulate a detailed action plan to raise awareness of the AD organisations use of a chemical substance with external stakeholders, to work collaboratively in terms of advocacy and joint responses from industry to chemical regulators.

6.5.7 Application of PDCA Continuous Improvements

The framework should not be considered as a one-time activity, the data ingested into the data model will continually evolve over time as new information becomes known, as shown in Figure [2-25]:

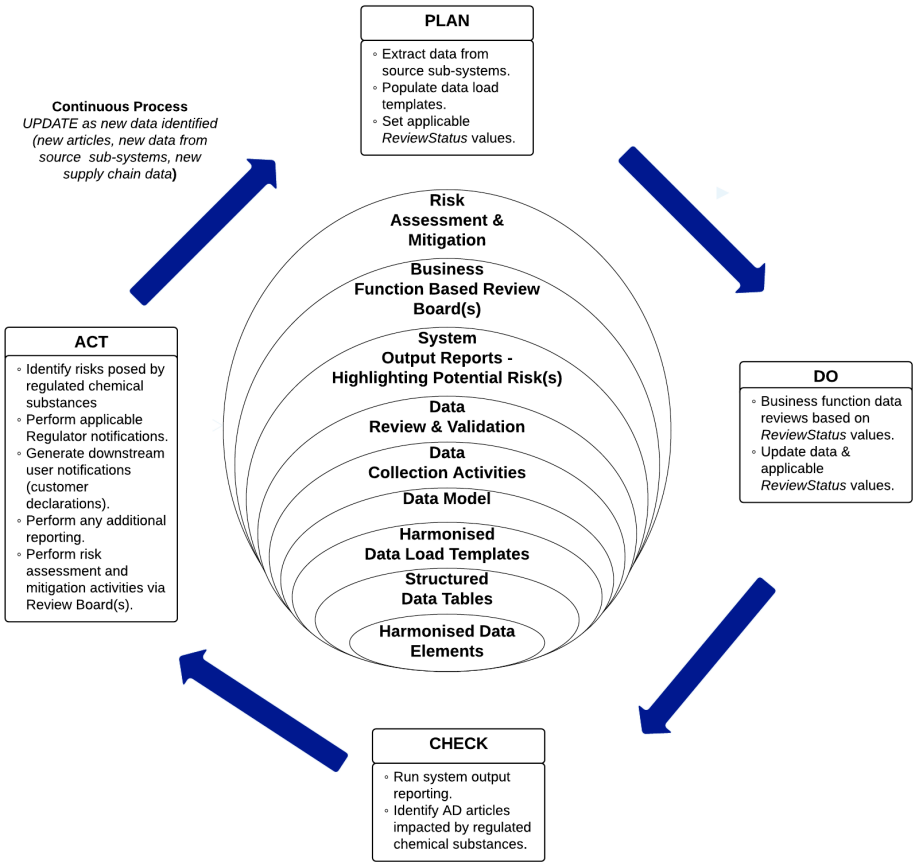


Figure 6-25: Continuous Data Flows Within Framework

6.5.8 Data Maintenance Activities

Data maintenance activities are defined in Appendix [16].

6.6 Framework Implementation Plan

This section outlines an implementation plan for the framework as shown in Figure [6-25]. The implementation plan is shown based on logical sequence of tasks defined against each of the research questions shown in chapter 1, the research questions were then further aligned into an implementation plan, using standard workflow steps as defined in standard CMMI terminology (CMMI Wiki, 2019; CMMI Institute, 2020). The timescales shown in the implementation plan, will vary between AD organisations depending on internal system alignment to the: (1) definitions and assumptions; (2) detailed stakeholder analysis; (3) data model, data elements and data templates; (4) achieving agreement from

stakeholders to provision data in a data load template and become engaged in the review board process.

The data load templates provide the source data, which is then ingested into either of the resultant application(s), which then provide system output reports that depict potential impacts posed by chemical regulations. As part of the data load template update / new data / data maintenance processes, different review status fields may be updated by applicable business functions, to denote whether a given data record requires action or has had actions completed against them, this information is then displayed within the system output reports, where applicable review boards may review the data and undertake risk mitigation activities as deemed applicable.

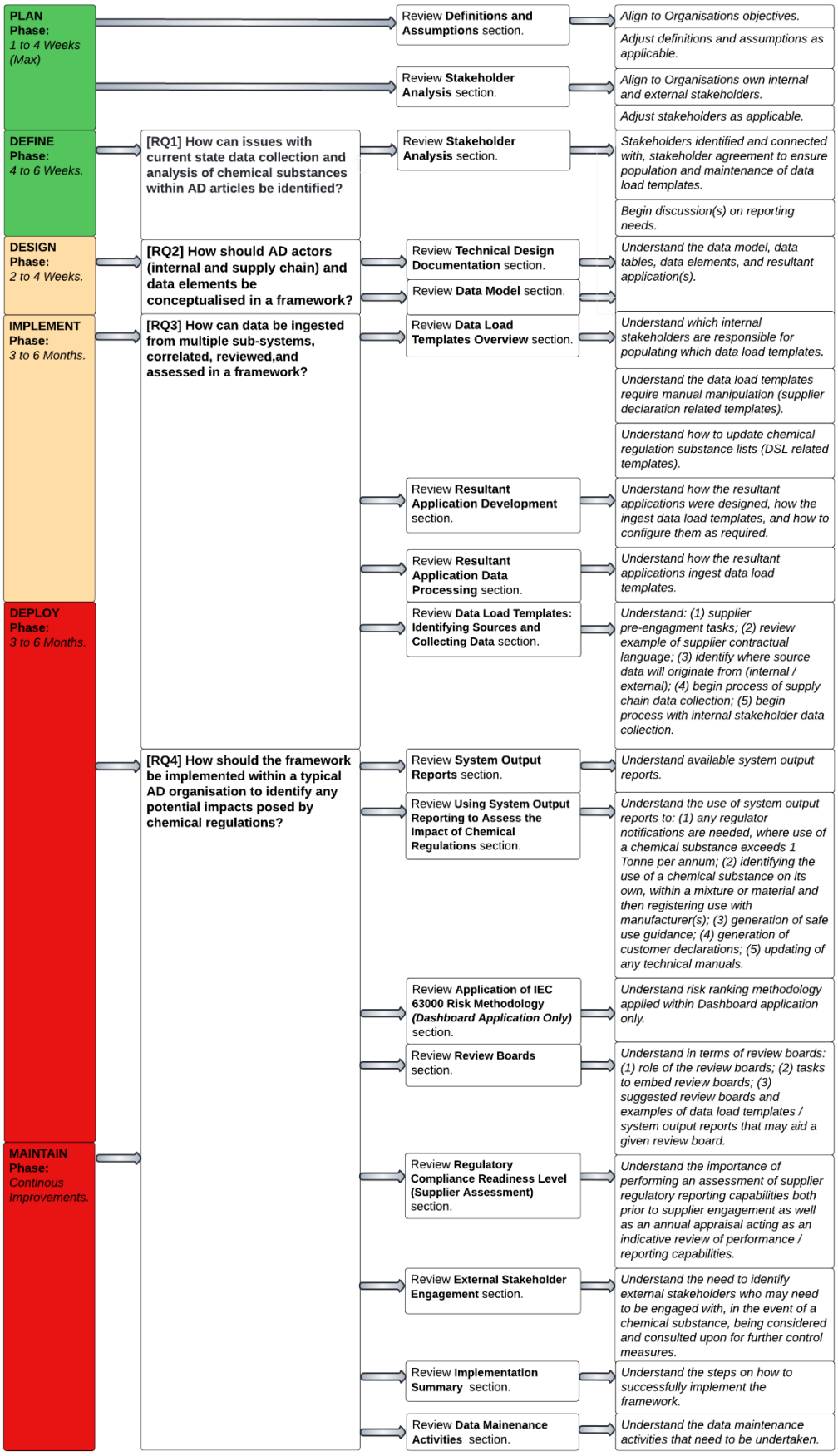


Figure 6-26: Framework implementation plan

6.7 Chapter Summary

In order to effectively identify the impact of chemical regulations on the AD sector, requires: (1) a data model that defines the harmonised data elements against which information needs to be captured against; (2) harmonised data load templates which support the data collection activities; (3) information captured in the data load templates ingested into an application which has the data model defined, which by design is platform agnostic, meaning it is not limited to the two resultant applications presented in this research study; (4) following data ingestion, the application is then capable of generating system output reports, identifying both workflow status actions, which support the clarity of a given data record (awaiting action / reviewed / potential risk action); (5) the prescribed review board was defined as a means of ensuring any potential risks are reviewed in a consistent manner, using information identified in a system output report; (6) finally, external stakeholders were defined to support the identification of follow-on activities where chemical substances become proposed for further control measures.

Chapter 7: Application of Data Model

7.1 Introduction

This chapter examines the effects of chemical regulations on the AD sector by performing a simulation activity using a fictional airframer with representative test data populated into the data load templates. The structure of this chapter is shown in Figure [7-1].

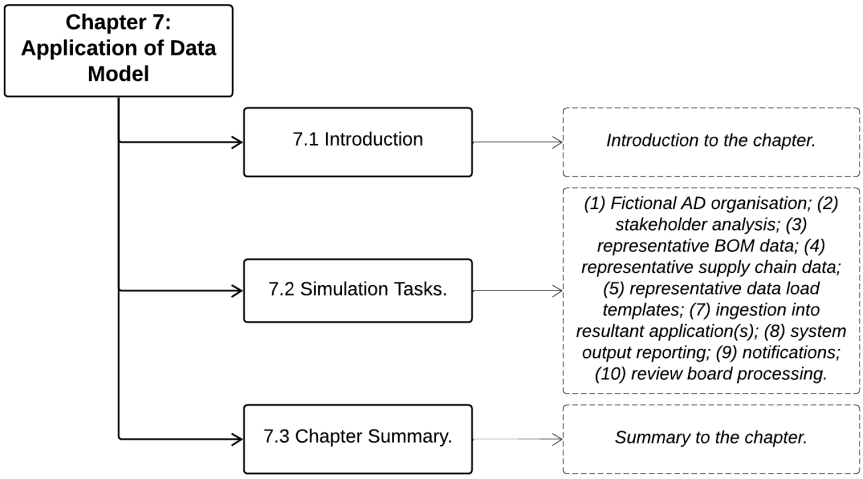


Figure 7-1: Appliction of Data Model Structure

7.2 Simulation Tasks

Figure [7-2] depicts a high-level summary of potential implementation paths: (1) standard implementation path where the proposed steps involve establishing the entire chemical substance reporting system, which are presented in more detail in Appendix [22]; (2) simulation path, as explored in the context of this chapter.

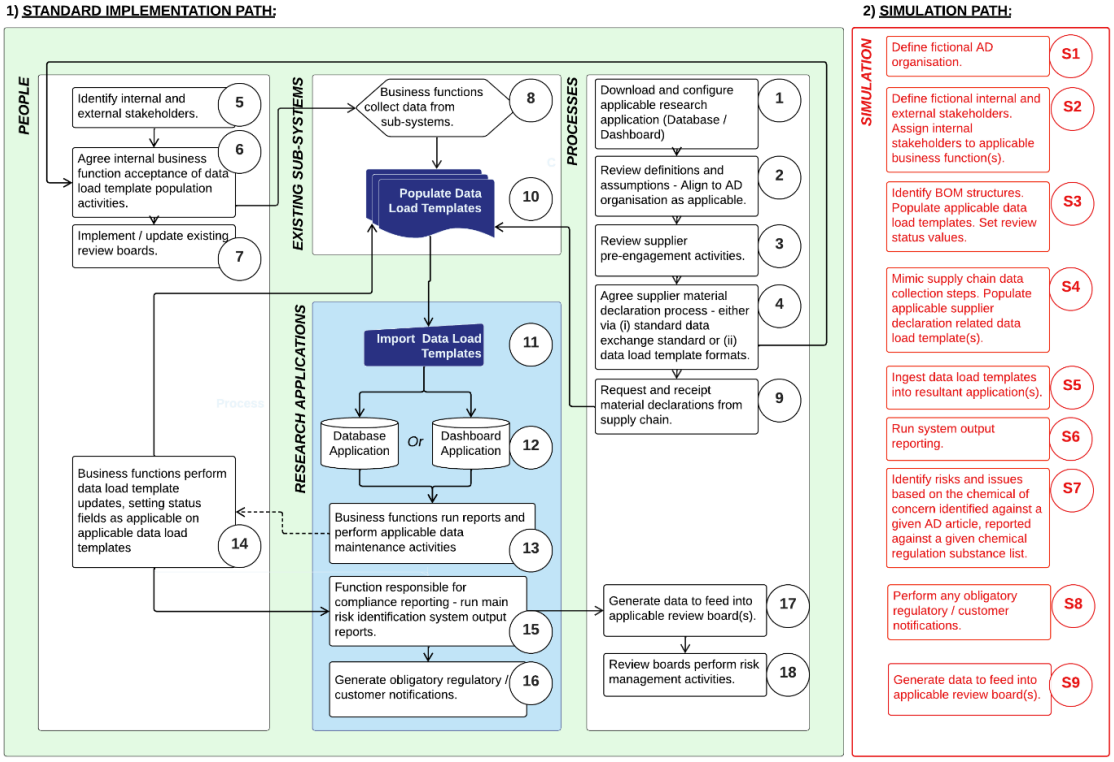


Figure 7-2: High-Level Implementation Path Overview

7.2.1 Task S1: Define Fictional AD Organisation

7.2.1.1 Ace Planes

Ace Planes was defined as the fictional AD organisation, against which simulation testing would be conducted against, as shown in Table [7-1].

Table 7-1: Ace Planes - A Fictional AD Organisation (Airframer)

Description	**Description**
Airframer name	Ace Planes.
Airframer established	December 25th, 2010.
Airframer location	Ace Planes is head quartered in Derby, United Kingdom.
Airframer number of employees	1,250 direct employees with up to 150 temporary contract employees.
Airframer annual turnover	£400M per annum.
Airframer main article as sold	Derby Aircraft Series – Next Generation – Narrow Body Aircraft: DAS-NG-100-NBA
Airframer main article as sold type	Narrow body, 100-seater, short to medium haul aircraft.
Number of jet engines on aircraft	2 Jet engines configured from multiple jet engine manufacturer as desired by the client.
Aircraft certification date	1st November 2017.
Number of aircraft in service	8 aircraft sold to 6 clients in active use, with spare consumable parts sold to support repair and maintenance activities.
Number of aircraft on order	6 aircraft on order to 6 clients.

7.2.2 Task S2: Define Fictional Internal and External Stakeholders and Roles

Fictional stakeholder names and roles were generated and defined to applicable internal business functions, where they were assumed as having work assigned to them, which could then via the ReviewStatus field, then be identified as awaiting action, reviewed with applicable status field. The information will be informed by the relevant business functions identified as being responsible for the data maintenance of a given data load template.

7.2.3 Task S3: Identify BOM Structures

The original aim for representative test data generation was estimated as being a 2-month period. The actual elapsed time, was longer than anticipated as the representative test data creation activities, themselves involved the creation of application articles, assemblies, defining definitions, supplier declarations, etc. In addition to which, whilst generating representative test data, which was loaded onto the data load templates, amendments were made to the data load templates such as the author defined MS-Excel formulas to calculate data, additional data elements being captured, and adjustments made to applicable system output reports. Figure [7-3] shows the elapsed actual representative test data creation phases conducted in terms of resultant representative test datasets being generated.

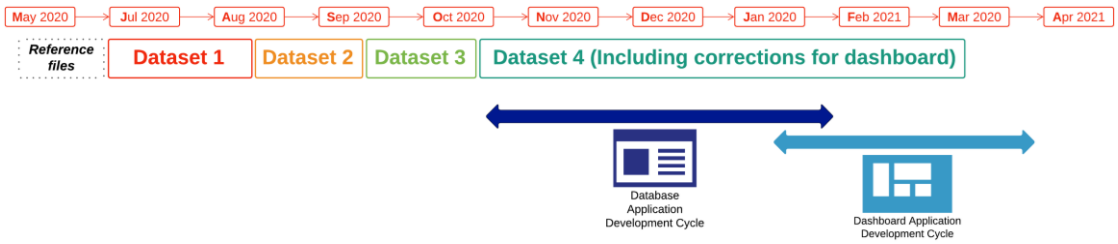


Figure 7-3: Representative Test Dataset Creation (Elapsed Time)

The authors original expectation was that the data template files could be created with representative test data generated within 6 weeks, the data template files took nearly 6 months to complete. The increased duration was attributable to: (1) generation of a baseline aircraft BOM; (2) iterative expansion and review of data being captured within the data load templates, led to expanding of the data load templates, additionally merging some tables from the conceptual design phase; (3) additional data fields were implemented as a result of: (i) EU GDPR requiring additional data separation and security; (ii) emerging additional data fields that required reporting into the ECHA SCIP database, as an outcome from EU WFD 2018/851; (iii) capturing values for EU UFI codes

generated in the EU PCN system for mixtures which contain any known hazardous chemical, and finally; (iv) known data fields to be implemented within the UK REACH-IT system to be implemented by Q3, 2021.

7.2.3.1 Representative Test Datasets

In the context of the research study, the representative data evolved as a collection of datasets, additional representative data was being generated and tested as part of the application / dashboard development processes, as shown in Figure [7-4].

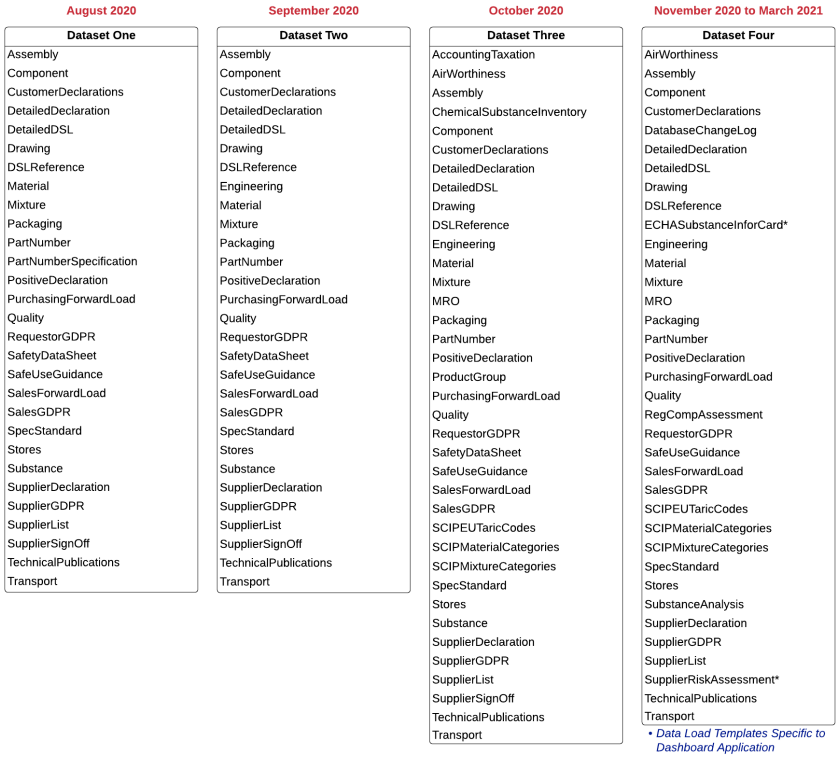


Figure 7-4: Dataset Summary

Dataset 1 consisted of 29 separate data load template files, consisting of 455 individual data fields. Dataset 2 consisted of 29 separate data load template files, consisting of 469 individual data fields. Dataset 3 consisted of 37 separate data load template files, consisting of 567 individual data fields. Dataset 4 consisted of 35 separate data load template files, consisting of 504 individual data fields.

7.2.4 Task S4: Mimic Supply Chain Data Collection Steps

Applicable data load template files updated as part of Task S5, see Table [7-2], cover these steps: *SupplierList*, *SupplierDeclaration*, *SupplierGDPR*, *SupplierRiskAssessment*, *PositiveDeclaration*.

7.2.5 Task S5: Ingest Data Load Templates

Table [7-2] defines examples of source systems which may be utilised by an AD organisation to collect the required data to populate data load templates.

Table 7-2: Summary of Generated Representative Test Data

Data Load Template Name	Example of Source System(s)	Data Elements Captured	No of Representative Test Data records
Airworthiness.	• Aircraft logbook of initial released state of the aircraft, detailing critical / life-limited and serialised article numbers which must be maintained by both the airline, the aircraft manufacturer and MRO organisations carrying out repairs. • Engineering design systems and ERP systems provide source data.	• 14.	• 5,800 records.
Assembly.	• Engineering configuration management systems (PDM, PLM).	• 19.	• 111 assemblies.
ChemicalSubstanceInventory.	• Physical inventory check.	• 11	• 111 substances, mixtures, materials.
Component.	• Engineering configuration management systems (PDM, PLM).	• 19.	• 334 components.
CustomerDeclaration.	• Generated from system output reports detailing articles that have been reviewed as containing any substances of concern for a given chemical regulation.	• 25.	• 12,539 statements. • 347 articles. • 6 customers.
DatabaseChangeLog.	• Updated as changes applied to the application.		
DetailedDeclaration.	• Supplier declarations collected using internal templates or industry data exchange formats (IPC-1752A, IPC-1752B, IPC-1754, IEC62474, MS-Excel spreadsheets, other).	• 42.	• 127 declarations. • 30,152 records.
DetailedDSL.	• Detailed reportable substance lists extracted from published regularity lists. • Regulation sources should be reviewed every 6 months for EU REACH, with other chemical regulations requiring at least an annual review.	• 8.	• 23 regulations. • 37 unique DSLs. • 14,369 records.
Drawing.	• Engineering design systems (CAD).	• 13.	• 672 records.
DSLReference.	• Index of reportable substance lists defined under DetailedDSL	• 7.	• 35 DSLs.
ECHASubInfoCardData.	• ECHA unique chemical substance information data card.	• 5.	• 6,164 substances.
Engineering.	• Engineering defined tasks to be undertaken during the article manufacturing cycle (manufacturing shop floor management systems, ERP).	• 10.	• 50 tasks.
Material.	• Materials defined by the materials function (materials management systems, Granta MI).	• 8.	• 14 materials.
Mixture..	• Formulation and mixtures defined by the materials function (materials management systems, Granta MI).	• 11.	• 235 mixtures.
MRO.	• MRO defined repair schemes, repair tasks and specifications available for repair operators to use.	• 11.	• 85 repair tasks.
Packaging.	• Defined packaging types for shipping articles (ERP).	• 4.	• 31 types of packaging.

Data Load Template Name	Example of Source System(s)	Data Elements Captured	No of Representative Test Data records
PartNumber	• Engineering configuration management systems (PDM, PLM).	• 19.	• 786 part numbers.
PositiveDeclaration.	• Following on declaration requested from a supplier following an earlier declaration identifying a chemical of concern (earlier identified supplier declaration detailing the presence of a chemical of concern).	• 38.	• 58 positive declarations. • 41 suppliers. • 335 part numbers.
PurchasingForwardLoad.	• Future supply chain purchase orders for articles (ERP).	• 15.	• 199 purchase orders. • 58 suppliers. • 531 part numbers.
Quality.	• Procedures and policies defined by the Quality function.	• 9.	• 13 quality procedures.
RegCompAssessment.	• Regulatory compliance function generated assessment of a chemical substance rated against a chemical regulation.	• 26.	• 740 chemical substances.
RequestorGDPR.	• Regulatory compliance function team members requesting supply chain data, stored in a separate table to control PII data.	• 10.	• 3 employees.
SafeUseGuidance.	• HSE defined safe use guidance statements for a given chemical substance. • Data generated from HSE internal systems, ECHA information on chemicals (2020g) and / or supplier provided SDS / MSDS records. • Safe use format based on Collins Aerospace generic safe use statement structure (UTC, 2020b).	• 19.	• 111 safe use guidance records.
SalesForwardLoad.	• Future sales orders for clients (ERP).	• 10.	• 121 article sales records.
SalesGDPR.	• Regulatory compliance function team members requesting supply chain data, stored in a separate table to control PII data.	• 13.	• 6 customer records.
SCIPEUTaricCodes.	• EU Taric codes from the latest values released by ECHA extracted by the Regulatory Compliance function but reviewed for applicability by the accounting function. Over 20,000 EU tariff codes, were investigated (ECHA, 2020f; EC, 2020h)	• 17.	• 360 initial AD related EU tariff codes identified.
SCIPMaterialCategories.	• Material and mixture category codes extracted from the latest values released by ECHA (ECHA, 2020f).	• 3.	• 299 categories.
SCIPMixtureCategories.		• 5.	• 209 categories.
Stores.	• Stock records of articles physically held in stores (ERP).	• 15.	• 949 substances, mixtures, and articles • 45 suppliers.
SubstanceAnalysis.	• Details of substances, mixtures and materials as defined by internal specifications, customer specification and industry standards. Can include data extracted from SDS / MSDS systems (HSE internal systems, ECHA information on chemicals, supplier provided SDS / MSDS records, materials management systems, Granta MI).	• 32.	• 544 substance analysis records. • 509 unique substances, mixtures, and articles. • 456 specifications and standards.
SupplierDeclaration.	• Supplier declaration status records.	• 12.	• 129 declarations.
SupplierGDPR.	• Supplier PII related data stored in a separate table (ERP).	• 11.	• 71 suppliers. • 86 supplier contacts.
SupplierList.	• List of suppliers (ERP).	• 13.	• 504 suppliers.

Data Load Template Name	Example of Source System(s)	Data Elements Captured	No of Representative Test Data records
SupplierRiskAssessment.	• Suppliers assessed using IEC 63000 risk assessment methodology applied to AD suppliers.	• 54.	• 495 suppliers.
TechnicalPublications.	• Technical publications systems (ATA, S1000D type systems).	• 14.	• 1,761 publication statements. • 347 articles.
Transport.	• Stores defined methods of shipping article(s) to customers.	• 13.	• 115 transportation records. • 41 articles.

7.2.6 Task S6: Run System Output Reporting

Figure [7-5] presents a data summary in terms of: (1) AD article level (components, part numbers, assembly); (2) articles defined as being either critical, non-critical, or life limited; (3) identified as either make or buy; (4) BOM definitions identified as being either customer, supplier or service (legacy article) levels, where the remaining BOM type by default would be internally defined; (5) article level, contrasting against details of sales and purchase orders to define volume of articles on order and to be sold.

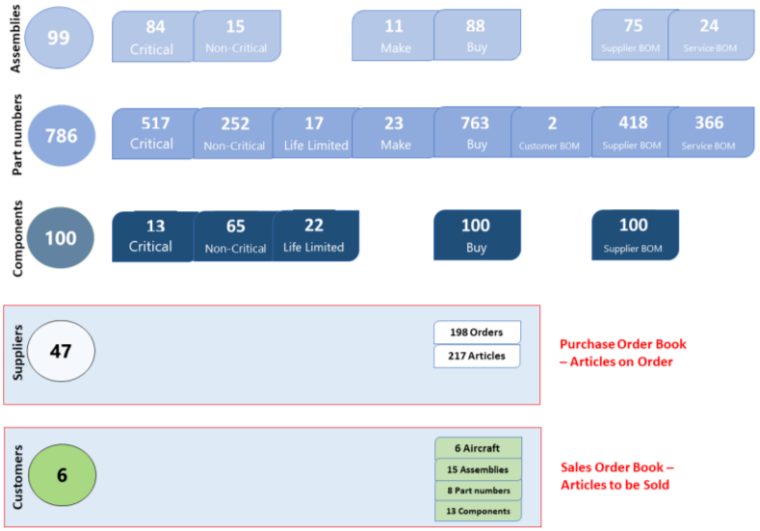


Figure 7-5: Representative Data: Article Type Data Summary

7.2.7 Task S7: Identify Risks and Issues

7.2.7.1 High-Level Summary of Representative Test Data

Figure [7-6] presents the initial state data summary, for Ace Planes, based on the ingested data load templates, with the applicable system output reports generating the data.

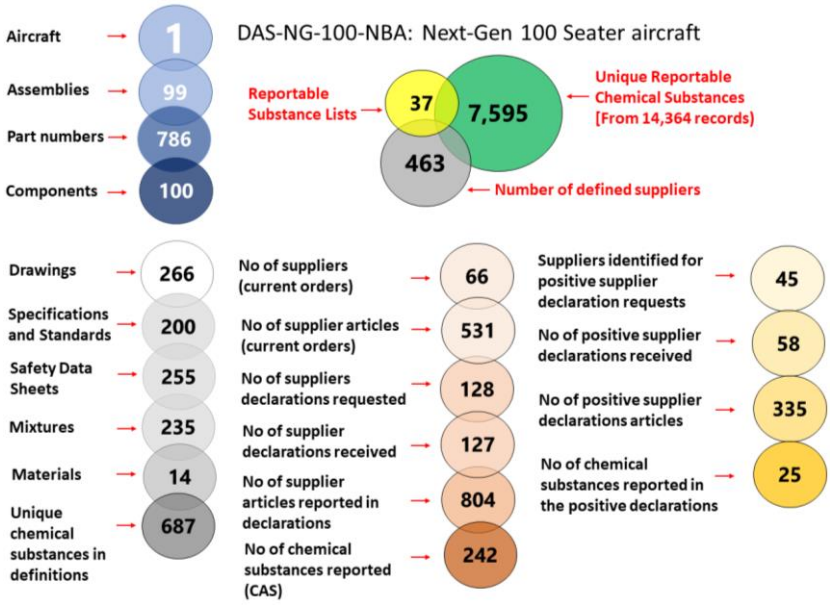


Figure 7-6: Ace Planes Simulation (Representative Test Data Generated)

7.2.7.2 Articles Identified as Containing Regulated Substances

The first simulation task was to identify applicable articles from internal definitions (*Drawing, Material, Mixture, SubstanceAnalysis*) and external supplier declarations (*DetailedDeclaration, PositiveDeclaration*) that contain chemical substances identified against chemical regulations, with the correct review status on applicable data load templates (*Component, PartNumber, Assembly, SubstanceAnalysis*).

7.2.7.3 Assess the Impacts of Chemical Regulations (EU REACH)

Figure [7-7] identifies the number of articles that contain chemicals identified as being reportable to downstream users as defined under the EU REACH Candidate List of substances, the applicable system output reports are available under the regulatory compliance function area within the application.

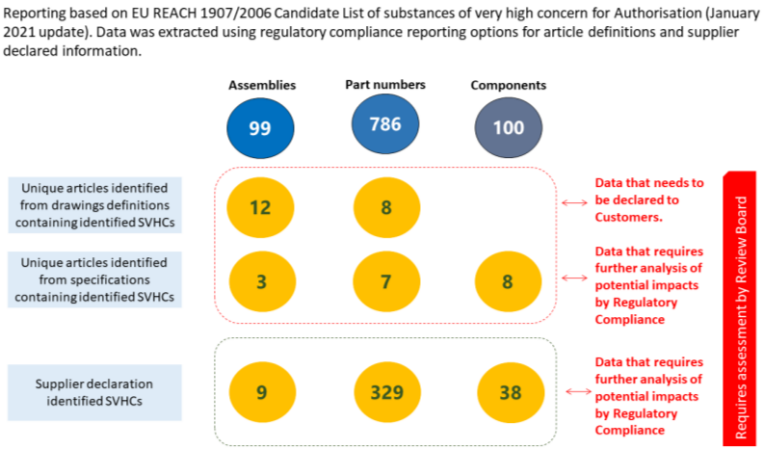


Figure 7-7: Articles Identified As Containing Substances of Concern (EU REACH Candidate List)

Examples of SQL queries generated to produce the applicable system output reports are shown in Appendix [20].

7.2.8 Task S8: Perform Obligatory / Customer Notifications

7.2.8.1 Assessing Regulatory Notifications (1 Tonne Threshold)

Run system output reporting: Database Application → Regulatory Compliance Function Menu → Additional Regulation Specific Analysis → 1 Tonne Threshold Reporting Analysis. *Note* – This activity was not undertaken as part of the simulation activity as it was assumed that this would be an activity that occurs because of the simulation activity.

7.2.8.2 Register Use of Chemical Substances with Manufacturers

Follow the steps outlined in the Identify Chemical Substances and Register Uses With Manufacturers section, to register the use of a chemical substance, mixture, or material with the applicable manufacturer, to be used in the event of a given chemical substance becoming further controlled via a chemical regulation. *Note* – This activity was not undertaken as part of the simulation activity as it was assumed that this would be an activity that occurs because of the simulation activity.

7.2.8.3 Generate Safe Use Guidance

As chemical regulation, substance lists are updated, review newly listed substances, and perform the steps defined in the Generate Safe Use Guidance Statements section.

7.2.8.4 Generate Downstream User (Customer) Material Declarations

Customer material declarations can be generated using process defined in the Perform Customer Declarations section.

7.2.8.5 Update Technical Publications

Upon creation of the safe use guidance for chemical substances, perform the steps defined in the Update Technical Publications section.

7.2.9 Task S9: Review Board Processing

Applicable review boards, once established are assumed to review applicable system output reports, considering the data reported in terms of the scope of a review board (materials, purchasing, design, etc). Table [6-12] outlined review boards and anticipated data load template data in the form of applicable system output reports defined in Table [6-9]. Where applicable additional analysis undertaken and presented to a review as

described in: (1) contractual language section; (2) Regulatory Compliance Readiness Level section, and; (3) the author adapted IEC-63000 methodology. *Note* – This activity was not undertaken as part of the simulation activity as it was assumed that this would be an activity that occurs because of the simulation reporting taking place.

7.3 Chapter Summary

The aim of the simulation activities undertaken in this chapter were to: (1) ensure data can be entered onto the applicable data load templates; (2) ensure data entered was capable of identifying articles grouped as components, part numbers and assemblies; (3) ensure that the data load templates could be imported into the application(s); (4) ensure that the application generated system output reporting is capable of identifying potential risks posed by chemical regulations; (5) generate reporting to be used in review board assessments as shown in Table [6-9], where appropriate risk assessment and risk mitigation activities can then be undertaken. To this end, the simulation activities successfully completed its intended objectives. External activities to the simulation, which were not tested: (1) performing regulatory notifications, where a substance is identified as being used on its own, within a mixture, material or on a finished article above an annual 1 ton threshold level; (2) registering the use of a chemical substance with the applicable manufacturer; (3) generation of safe use guidance for the identified chemical substance; (4) generation of downstream user (customer) declarations; (5) updates to existing technical publications.

Chapter 8: Conclusion

8.1 Introduction

This chapter presents the key findings from the research study are summarised together with contributions to knowledge, limitations of research and potential future areas of research. The structure of this chapter is shown in Figure [8-1].

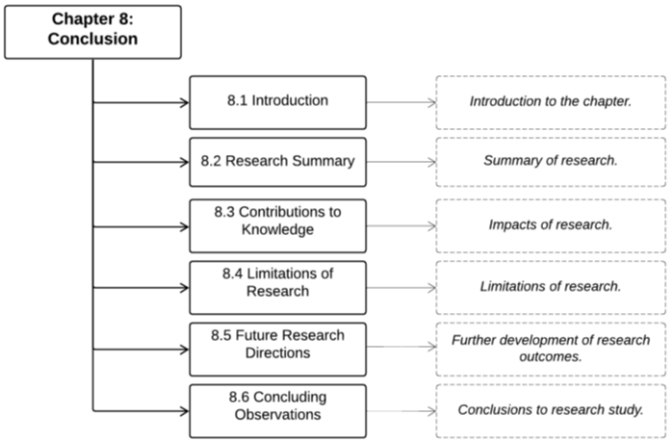


Figure 8-1: Conclusion Structure

8.2 Research Summary

The research problem that this research study has attempted to address, pertains to accurately identifying AD articles that face potential risks posed from using chemical substances that may come into scope of a given chemical regulation. To achieve the research aim, and research objectives, four key research questions research questions as shown below:

- [RQ1] How can issues with current state data collection and analysis of chemical substances within AD articles be identified?
- [RQ2] How should AD actors (internal and supply chain) and data elements be conceptualised in a framework?
- [RQ3] How can data be ingested from multiple sub-systems, correlated, reviewed, and assessed in a framework?
- [RQ4] How should the framework be implemented within a typical AD organisation to identify any potential impacts posed by chemical regulations?

These research questions formed a critical core to this research study.

8.3 Contributions to Knowledge

Table [8-1] details the key contributions of this research study:

Table 8-1: Summary of Key Contributions to Knowledge

Research Element	Description	Applicable research questions	Summary of key contributions
Chapter 1: Introduction.	Short introduction to the research study.	[RQ1], [RQ2], [RQ3], [RQ4].	Set out **author background, research motivation, research aim, research objectives; research questions** [RQ1 to RQ4] as shown in section 1.4.3, organization of thesis.
Chapter 2: Literature Review.	Detailed review of literature focused on addressing the four key research questions.	[RQ1]	**Identification of what an article is considered as under a chemical regulation**. Examination of the **global chemicals sector**. Examination of **global chemical regulations and initiatives**. **Examination of the global AD sector.** **Current state issues with AD sector supply chain data collection activities**.
		[RQ2]	**Identification of AD organisation internal stakeholders**. **Identification of Typical AD sector supply chain actors**. **Identification of complex AD buyer supplier relationships.** Examination of data exchange standards Review of supply chain data collection in non-AD sectors
		[RQ3]	**Identification of research context.** **Identification of effective identification and chemicals substances.** **Identification of impacts posed by chemical regulations.**
		[RQ4]	**Outcomes from initial industry consultation on supply chain data collection**. Industry readiness levels assessment.
Chapter 3: Research Programme Development	Overview of articulated research strategy.	[RQ1], [RQ2], [RQ3], [RQ4].	Holistic overview of how research strategy was formed from aim, objective, objectives into final research strategies, worldviews, etc.
Chapter 4: Conceptual Framework Design	Key mid-cycle research design.	[RQ1]	**Identification of AD sources of data (identification of internal sources of data, sources of substance related data, core chemical regulation substance lists)** **System context diagram - identification of initial data flows across internal systems, roles of internal actors.**
		[RQ2]	**Identification of AD technical design authority**, the party responsible for AD article design, definitions and potentially selection of chemical substance, mixtures, and materials

Research Element	**Description**	**Applicable research questions**	**Summary of key contributions**
			AD stakeholder analysis **identification of AD specific stakeholders and roles.** **Analyzed AD internal stakeholders and influences** (Mendelow matrix)
		[RQ3]	Evolution of research philosophy from theoretical to conceptual framework/ **Identification of theoretical framework was seen as capturing key data elements and the identification of stakeholders.**
		[RQ4]	**Conceptual framework development** (Data, data analysis, risk identification, risk mitigation) design and high-level roadmap. **Resultant applications to ingest data and perform reporting.** **System output reporting - reports generated by resultant applications.** **Review boards - conceptual review boards used to review risks and perform risk mitigation activities.** Application of Plan-Do-Check-Act - continuous review and improvement of design **Validation and verification of framework using expert feedback via Delphi studies.** **The need for a regulatory compliance readiness level.** **Simulation of conceptual framework by ingesting and testing with representative data**.
Chapter 5: Delphi Studies Validation Process and Results.	Two distinct Delphi studies: (1) the data model, and (2) system output reporting	[RQ2]	Delphi study 1: validation of supply chain actors.
		[RQ3]	Delphi study 1: validation of data elements and data model.
		[RQ4]	Delphi study 3: System output reporting as a feedback mechanism.
Chapter 6: Detailed Framework Design	Detailed conceptual framework.	[RQ1]	Detailed definitions and assumptions. Detailed internal stakeholder analysis (SIPOC). Detailed external stakeholder analysis (SIPOC).
		[RQ2]	**Technical design documentation** (requirements, design, application, requirement traceability, testing and user documentation). **Data model** (high-level data model; substance level data tables; article level data tables; supplier level data tables; customer level data tables, other data tables). Core logic **identify chemical substances that appear on AD articles from definitions, specifications or supplier declarations which are then contrasted with chemical regulation substance lists**.
		[RQ3]	**Harmonized data load templates** which replicate data tables, **supporting the collection of data using standard MS-Excel spreadsheets, with little customization other basic calculation formulas. Provide a standardized format to collecting data** which can then be ingested into the resultant applications. Data load templates allow **for data creation, status setting** (for additional internal reviews if applicable). **Resultant application(s) designed to ingest data contained in applicable data load templates.**

Research Element	Description	Applicable research questions	Summary of key contributions
			Supplier pre-engagement activities (supplier contract language). **Identification of internal and external data collection activities.**
		[RQ4]	**System Output Reporting**, reports generated by resultant applications to identify potential risk(s) posed by chemical regulations (registrations, notifications, declarations, review board actions). Using system output reporting to **assess the impact of chemical, based on data records being reviewed and identified by review status value setting** as being in scope for a given chemical regulation. Where **data maintenance activities take care of any data refreshing activities**. **Extended risk analysis via the use of IEC 6300** risk (only for dashboard resultant application). Suggested **review boards to establish an internal process to perform regular reviews of potential risks** which have been identified by the conceptual framework. **Identification of potential external stakeholders to engage with**, in the event of a chemical substance coming into scope for further regulatory control measures. Working collaboratively with other AD or non-AD actors to justify the use of the chemical substance. **Continuous improvements** to design applied via PDCA. **Data maintenance activities**, end to end system maintenance tasks identified. **Framework implementation plan**, detailed steps to implement the conceptual framework.
Chapter 7: Application of Data Model	Creation of representative test data and simulation via conceptual framework (resultant applications)	[RQ1]	Task S1: Define fictional AD organisation. Task S1: Define fictional internal and external stakeholders, and roles.
		[RQ2]	Task S3: Identify BOM structures.
		[RQ3]	Task S5: ingest data load templates.
		[RQ4]	Task S4: Mimic supply chain data collection steps. Task S6L Run system output reports. Task S7: Identify risks and issues. Task S8: Perform obligatory / customer notifications. Task S9: Review board processing.
Chapter 8: Conclusion	Research summary, key contributions, and limitations of research study.	[RQ1], [RQ2], [RQ3], [RQ4].	Harmonized methods to support the identification of chemical substances in AD articles which may be under the scope of a chemical regulation and therefore require additional activities to be undertaken by the AD organization.

8.4 Limitations of Research

The limitations of the research study are examined in Table [8-2]:

Table 8-2: Research Limitations with Suggested Mitigation Actions

Description of Limitation(s)	**Suggested Mitigation Action(s)**
AD organisation internal stakeholders may be different from those identified within the stakeholder analysis.	Identify divergences by reviewing detailed stakeholder analysis, adjusting as required.
Delphi study 1 identified AD organisation may adopt different approaches to identifying definitions, from the originally assumed methods.	This limitation would be at organisational level, but the data model, data tables and data elements allow for flexibility in data collection with any adjustments to system output reporting undertaken updating the applicable query statements.
Chemical regulations regularly update chemical substance lists on a regular cadence, where if applicable updates to data load templates are not undertaken on a regular cadence, validity of system output reports may cause arise.	Review chemical regulations on a regular cadence and perform data maintenance activities.
The resultant database application, MS-Access database has a limitation when trying to generate and query multi-level BOMs. The issue is peculiar to MS-Access in that the database will allow small BOMs to be ingested and queried but does not work well with BOM structures above 3 levels, without the use of lots of customised scripting.	If maintaining the resultant database application, generate the required SQL query statements would have resulted in a customised set of attributes (methods, classes) which would have made the database application become heavily customised. Ingest the data model into an Oracle or SQL server database, adjust as required.
The system output reports may not meet the needs of the AD organisation, in which case the AD organisation may wish to update / create new data elements and data tables.	Review technical design documentation. Any changes to elements will require a review of the query statements used to generate the system output reports.
The review board processes are conceptual and may not be applicable to every type of AD organisation.	The review board process should be considered as being aligned to existing AD article review procedures where possible or implemented as suggested.
Different external stakeholders may exist in relation to a given chemical substance coming into scope for further control measures.	The initial list of external stakeholders needs to be reviewed on a regular cadence in relation to a given chemical substance being proposed for further regulatory control measures.
Updates to existing buyer-supplier contract terms may not be achievable in the short-term, as the duration of existing contract terms may be for several years.	Review and revise buyer-supplier contract terms when feasible to do so.
Conceptual regulatory compliance readiness level may contain missing features.	The compliance regulatory compliance readiness level is conceptual. It needs further development with industry to develop more harmonised supplier assessment criteria and scoring.

8.5 Future Research Directions

Future research directions are examined as follows:

- Overall conceptual framework: illicit additional feedback from AD organisation(s), review and amend conceptual framework as required.
- Chemical regulations:
    - (1) Keep abreast of upcoming regulatory proposals and their potential impacts anticipated;
    - (2) Participate in applicable workshops and consultations;
    - (3) Monitor and update applicable substance lists;
    - (4) Adjust resultant application(s) and system output reporting as required.
- Resultant application(s):
    - (1) Data maintenance;
    - (2) Further enhancements;
    - (3) Investigate further development utilising either Oracle or MS-SQL server database.

8.6 Concluding Observations

The research aim of this thesis was stated as being '**to develop a conceptual framework enabling identification of articles (products) potentially at risk from chemical regulations supporting decision making processes for AD organisations'**.

Manufacturers who produce, distribute or market any kind of physical article are impacted by different regulations and standards. Chemical regulations exist to monitor, control, and restrict the use of hazardous chemicals, to achieve this, chemical regulations include obligations to report data against an identified list(s) of hazardous chemical substances, whether they are used on their own, within mixtures, materials and articles.

As greater scrutiny arises over the use of hazardous substances, from regulations and standards, industry must record the use of chemical substances, mixtures, or materials, both within internal facilities and across a supply chain for procured products. AD organisations need to identify applicable hazardous chemical substances, contained within AD articles, in order fully understand the associated impacts and obligations in a systematic manner.

Without collating and analysing such data, AD article manufacturers remain face business continuity risks as chemical substances may become restricted outright or banned in a specific use case, which presents the risks of being unable to manufacture or place AD articles onto a marketplace.

The traditional focus for AD organisations has been to ensure product type approval is granted, which is based on having an audited quality management system, that includes a configuration management capturing change requests and recording changes to AD articles. Attaining product type approval is prerequisite requirement for any manufacturer of AD articles. Additional regulatory body approval processes are required for critical and life-limited AD articles. When these types of AD articles are scrutinised by a regulatory body, priority is placed against the fit, form, and function of a given AD article, which are aligned to ensuring safety and durability of the aircraft where they are consumed. Substance related information is assessed within this approval state, but only at the initial approval state for a given AD article, as changes occur to the material composition, revalidation is not required for the AD article, unless it results in a change to the fit, form and function of the AD article, which should under normal circumstances result in a new number for the AD article.

AD organisations whilst having long lead times for design, test, approval, and implementation, must address the implications of chemical regulations, or risk facing continual business continuity issues where AD articles may be restricted from the marketplace or the ability to manufacture a given AD article becomes severely restricted when control measures are placed against a chemical substance.

Chemical regulations impact all business function areas, not just the assumed materials, design, and engineering functions. To fully understand the impact of chemical regulations, AD organisations need to adopt a whole system view of the potential impacts, as regulated chemical substances raise business continuity risks, such as:

- Identification of where hazardous chemical substances are being consumed within AD articles;
- Revalidation of existing occupational health risks for internal employees from the HSE / EHS functions.

- Assessment of existing inventory and capability to produce AD articles which requires identification of potential sales of AD articles impacted by a chemical regulation, contrasted with procurement of necessary raw materials and potential 'last time buys' of raw materials where chemical substances become restricted from a certain date;
- Investigation of alternative substance use, with applicable design and testing required, which in the AD sector can take several years due to long lead times for testing and approval;
- Generation of obligatory customer declarations and / or notifications to regulators regarding the use of a regulated chemical substance.

This research study, whilst simple in the context of the research problem, evolved from a conceptual data model ingesting data and generating system output reports, into a robust systematic framework, which was expanded as new contexts from the Delphi studies and indeed new obligations from new regulations arose, in particular:

- Author participation in trade association engagements with the European Commission, where the author was asked to represent both the Electronics and Medical Device sectors when discussing the introduction of the ECHA SCIP database;
- Author participation within the ECHA SCIP IT user group where the author helped to develop and test software integrations;
- UK withdrawal from the European Union (Brexit) which facilitated the need for a UK REACH like system to report the use of hazardous chemicals;
- Emerging reporting requirements from the EU Green Deal;
- Emerging global requirements which required the identification of country of origin information, this information was previously considered as part of critical raw material reporting, however, with the advent of the COVID-19 pandemic, these data elements capturing country of origin related data became critical;
- Participation in research conferences which identified new concepts, which were then integrated as logical extensions to the research study, most notably on the use of smart labelling technologies integrated with IoT devices within a smart factory to collate chemical substance related information.
- Generation of representative test data identified gaps in data collection which needed to be addressed to support the use of the data templates and system output reports. These

gaps were implemented as new data elements, verified with applicable Delphi study 1 respondents, then tested with representative data.

AD organisations contain multiple sub-systems storing disparate data managed by multiple business functions. Where one would assume the required data needed to support chemical substance reporting would be contained within either: (1) an engineering design system such as a PLM, or; (2) manufacturing scheduling system such an ERP, or; (3) material definition systems containing details of specifications and associated chemicals, multiple sub-systems may exist within the AD organisation, which store the required data elements.

The process of data extraction from internal sub-systems requires review and validation analysis from applicable business functions to confirm the cleanliness and accuracy of the data, this was handled using the ReviewStatus field. Without the review and validation analysis, the AD organisation is likely to find several potential false positive reporting occurring because of:

- Multiple AD article numbering systems in place, resulting in complex identification of the correct internal article number to its associated internal / supplier article numbers;
- Material definition systems defining specifications which containing several optional and mandatory chemicals;
- Supplier declared data may report chemical substances which are identified by a supplier as being present on an AD article, which, may not appear on the finished AD article, due to actually being transitory process chemical substances.

Implementing the review and validation process supports the correct identification of:

- The chemical substance being present on a finished AD article greater than a nominal concentration threshold of 0.1%;
- Generation of required safe use guidance statements needed for identified hazardous chemicals;
- Generation of notifications to regulators where a chemical substance is being consumed on its own, within a mixture, material, or AD article greater than 1 tonne per annum;
- Generation of notifications informing customers regarding the presence of hazardous chemical substances with the applicable safe use guidance, which may be transmitted:
  - As part of the standard documentation submitted with a physical AD article;

- Displayed on the AD organisation website;
- Inserted into the AD organisations technical publications system(s).

- Additional reporting obligations based on the identification of hazardous chemical substances, such as ECHA SCIP database reporting.

A key design intent of this research study was to define the required data elements, data tables, data model and system output reports needed to support accurate identification of chemical substances contained within AD articles against regulated chemical substances.

The framework design offers flexibility in terms of actual implementation which can be undertaken: (1) against existing AD organisation internal systems such as PLM, ERP, or data warehouse type systems; (2) utilising the database application collating and reporting data; (3) utilising the dashboard application collating and reporting data.

Without the prescribed framework being used to identify AD articles impacted by a chemical regulation, an AD organisation may not be aware of any potential business continuity risks, until it is too late, and the chemical substances become further controlled or restricted by which time other competitors within the AD sector, who do have reporting capabilities are: (1) investigating the use of authorisations to permit continued use of the chemical substance, or; (2) already examining the use of potential alternative chemical substances.

Where AD organisations have existing systems to support the identification of chemical substances in AD article, such systems are likely to lack to: (1) a whole system view as defined in the prescribed framework; (2) use of harmonised data elements, data load templates; (3) review and validation analysis; (4) review board risk assessment and risk mitigation activities. The prescribed framework may be utilised to enhance existing systems.

The framework if applied by AD organisations, enables clarification of assumed chemical substances in articles, which are based on assumptions on AD article types, and worst case assumptions based on material and process specifications containing mandatory and optional chemical substances. Whilst the focus of this study was to develop a framework to support the AD sector, the framework can be adapted to meet chemical substance reporting in articles for other industry sectors.

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Appendix

Appendix 1: Analysis of mean number of aircraft parts (1957-2019)

Note – Original sales values have been rounded to 2019 rates using https://www.dollartimes.com/inflation/inflation.php?

Appendix Table 1: Analysis of mean number of parts and sales values for aircraft (1957 and 2019)

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
Defence (aircraft)	Airbus	A310 MRTT	2003	No		2	214	8,889	47.4			A310 MRTT Wiki, 2019.
		A330 MRTT	2011	Yes		3	291	14,800	58.80			A330 MRTT Wiki, 2019.
		A400M Atlas	2013	Yes	213.37	4	116	6,400	45.1			A400M Wiki, 2019.
		CC-150 Polaris	1992	No		2	194	9,600	46.66			CC-150 Polaris Wiki, 2019.
		HC-144 Ocean Sentry	2009	No		6	6	2,898	21.41			HC-144 Wiki, 2019.
	Antonov	AN-32	1982	Yes	40.09	4	46	2,500	23.78			Antonov, 2019a.
		AN-71	1985	No			6		23.5			Antonov, 2019b.
		AN-72	1977	No		5	52	2,788	28.07			Antonov, 2019c.
		AN-74	1983	No		5	52	2,688	28.07			Antonov, 2019d.
		AN-132	2017	No		2	77	4,400	24.53			Antonov, 2019e.
		AN-148	2004	Yes	40.89	68	85	4,400	29.13			Antonov, 2019f.
		AN-158	2010	Yes	44.20	86	99	2,500	30.83			
		AN-178	2015	No	74.89	2	70	4,700	32.95			Antonov, 2019g.
	BAe	Nimrod MRA4	2004	No		2	4	11.119	38.6			BAe Wiki, 2019a.
	Boeing	737-AEW&C	2009	Yes		8	12	3,500	46.62			Boeing, 2019a.
		KC-46	2019	Yes	241.1	3	15	11,830	50.5			Boeing, 2019b.
		KC-135	1957	No	360.46	3	80	2,419	41.53			Boeing, 2019c.
		KC-767	2005	No	145	2	3	12,200	48.5			Boeing, 2019d.
		767-200ER (tanker)	2011	No		2	12	10,370	48.5			Boeing, 2019e.
		C-40A	2001	Yes	70		121	3,200	33.63			Boeing, 2019f.
		E-3 Sentry (AWACS)	1977	No	270	4	19	7,400	46.61			Boeing, 2019g.
		P-8A	2013	Yes	256.5	2	9		39.47			Boeing, 2019h.
		P-8I	2013	Yes	125	2	9		39.47			
	CASA / ITPN	CN-235	1988	No	74.02	2	53	4,355	21.40			CASA / ITPN Wiki, 2019.
	Dassault	Rafale	2001	Yes	119.20	1	2	3,700	15.27			Dassault Wiki, 2019a.

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
	EADS	CASA C-295	2001	No	40.42	2	75	4,587	24.46			EADS Wiki, 2019.
	Embraer	C-930 Millennium	2019	Yes	55	2	82	2,820	33.5			Embraer Wiki, 2019a.
	Kawasaki	C-2	2010	Yes	158.22	2	3	9.800	43.9			Kawasaki Wiki, 2019a
		P-1	2013	Yes	179.45	3	6	8,000	38			Kawasaki Wiki, 2019b.
	Leonardo	C-27J Spartan	1999	Yes	49.05	2	62	4,130	22.7			Leonardo Wiki, 2019a.
	Lockheed Martin	AC-130U	2007	Yes	261.44	3	13	4,100	29.79			Lockheed Wiki, 2019a.
		C-130H	1992	Yes	54.84	5	92	3,800	29.79			Lockheed Wiki, 2019b.
		C-130J Super Hercules	1996	Yes	273.33	3	92	3,334	29.79			Lockheed Wiki, 2019c.
		HC-130H	1959	No		5	7	8,334	29.8			Lockheed Wiki, 2019d.
		EC-130H Compass Call	1982	No	440.99	2	13	3,694	29.3			Lockheed Wiki, 2019e.
		EC-130J	1975	No	532.49	2	6	4,260	29.7			Lockheed Wiki, 2019f.
		KC-130	2004	Yes	96.88	4	92	5,250	29.79			Lockheed Wiki, 2019g.
		L-100-30	1965	No	248.90	3	4	2,470	34.25			Lockheed Wiki, 2019h.
		MC-130H Combat Talon II	1987	No	253.41	7	77	4,344	30.4			Lockheed Wiki, 2019i.
		MC-130J Combat Commando II	2011	Yes	77.14	2	77	5,556	29.8			
		WC-130	1962	No	406.16	5	5	2,963	29.79			Lockheed Wiki, 2019j.
	McDonnell Douglas	KC-10 Extender	1981	No	257.35	4	4	7,080	55.35			McDonnell Douglas Wiki, 2019e;
	Northrop Grumman	C-2A	1966	No	316.01	4	26	2,400	17.32			Northrop Grumman, 2019.
Summary data (mean value):					**$184.89M**	**7**	**55**	**5,067**	**34.37**			
Freight *(legacy dollar values rounded to 2019 rates)*	Airbus	A300-600F	1971	No	417.9	3		7,500	54.10			Airbus, 2019b.
	Boeing	747-8F	2008	Yes	419.2	3		7,630	76.3			Boeing, 2013; Boeing, 2019i; Boeing, 2019j; Boeing, 2019k; Boeing, 2019l.
		757-200F	1981	No	183.92	3	5	5,435	47.3			
		767F	1981	Yes		3		3,255	54.94		3,100,000	
		777F				3		4,970	63.7			
	Shaanxi	Y-8	1981	Yes		2	95	5,615	34.02			Shaanxi Wiki, 2019a; Shaanxi Wiki, 2019b.
		Y-9	2010	Yes		4	106	2,200	36.065			
Summary data (mean value):					**$340.34M**	**3**	**69**	**5,229**	**52.35**		**3,100,000**	

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
Business / Corporate	Airbus	ACJ318		Yes		8		7,800	31.45			A319 Wiki, (2019); Airbus, 2019c.
		ACJ319	1994	Yes	154.39			6,940				
	Boeing *(Max models are larger planes retrofitted).*	BBJ 747-8						16,436	76.3			Boeing, 2019y.
		BBJ 787-8					25	18,418	56.72			
		BBJ 787-9					25	17,566	62.81			
		BBJ 777-8						21,583	69.81			
		BBJ 777-9				138	172	20,372	76.7			
		BBJ MAX 7	1998	Yes	142.04	162	210	12,964	35.56			
		BBJ MAX 8	1998	Yes	154.2	178	220	12,297	39.52			
		BBJ MAX 9	1998	Yes	168.06	188	230	12,066	42.16			
	Bombardier	Global 5000	1998	Yes	50.44	4	13	9,630	29.5			Bombardier Wiki, 2019.
		Global 5500	1998	Yes	62.31	4	16	10,556	29.5			
		Global 6000	1998	Yes	46	4	13	11,112	30.3			
		Global 6500	1998	Yes	56	4	17	12,223	30.3			
	Cessna	M2	2013	Yes	5.15	1	7	2,871	12.98			Cessna Wiki, 2019.
		CJ2+	2013	Yes	7.04	1	9	3,298	14.53			
		CJ3+	2018	Yes	8.70	1	9	3,778	15.59			
		CJ4	2019	Yes	9.65	1	10	4,010	16.26			
	Dassault	Falcon 5X	2022	No	47	4	16	9,600	25.2			Dassault Wiki, 2019a; Dassault Wiki, 2019c; Dassault Wiki, 2019d; Dassault Wiki, 2019e; Dassault Wiki, 2019b.
		Falcon 6X	2022	No	47	4	16	10,200	25.68			
		Falcon 7X	2007	Yes	69.47	12	16	11,109	23.38			
		Falcon 8X	2016	Yes	62.99	12	16	11,945	24.46			
		Falcon 900	1984	Yes	111.11	8	19	7,400	20.21			
		Falcon 2000S	1995	Yes	49.51	4	19	6,020	20.23			
		Falcon 2000LXS	1995	Yes	58.91	4	19	6,020	20.23			
	Embraer	Lineage 1000	2009	Yes	59.63	4	19	8,500	36.24			Embraer Wiki, 2019b.
	Gulfstream	GI	1959	No		10	24	4,090	19.43			
		GII	1967	No	21	10	19	6,635	24.36			Gulfstream Wiki, 2019a; Gulfstream Wiki, 2019b; Gulfstream Wiki, 2019c; Gulfstream Wiki, 2019d; Gulfstream Wiki, 2019e; Gulfstream Wiki, 2019f; Gulfstream Wiki, 2019g.
		GIII	1979	No	37	12	19	6,760	25.32			
		GIV	1985	No		14	19	7,815	26.92			
		GIV-SP	1985	No		14	19	7,815	26.92			
		V C-37A	1997	No	36	15	19	10,186	29.4			
		G350	1985	No	34.2	12	19	7,038	27.23			
		G450	1985	No	41	12	19	8,056	27.23			

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
		G500	2014	Yes	46.5	12	19	9,630	27.78			
		G550	2004	No	61.5	14	19	12,501	29.4			
		G600	2014	Yes	57.9	12	19	12,040	29.29			
Summary data (mean value):					**$60.88M**	**28**	**40**	**9,926**	**32.19**			
Regional	Antonov	AN-148	2004	No	40.90	68	85	3,500	29.13			Antonov Wiki, 2019f.
		AN-158	2010	Yes	34.90	86	99	2,500	30.83			
	BAe	146/Avro RJ-100/RJ70	1983	No	33.46	70	82	3,870	26.19			BAe Wiki, 2019b.
		146/Avro RJ-200/RJ85	1993	No	23.02	85	100	3,650	28.55			
		146/Avro RJ-300/RJ100	1984	No	33.46	97	112	3,340	31			
	Bombardier	CRJ700	1999	Yes	63.36	66	78	2,553	32,3			Bombardier Wiki, 2019.
		CRJ900	1999	Yes	71.28	76	90	2,876	36.2			
		CRJ1000	1999	Yes	75.88	97	104	2,120	39.1			
	Comac	ARJ21-700	2007	Yes	49.80	78	90	3,700	33.46			Comac Wiki, 2019a; Comac Wiki, 2019b.
		ARJ21-900	2007	Yes	49.80	98	105	3,300	36.35			
	Fokker	70	1994	No		72	85	3,410	30.91			Fokker Wiki, 2019a.
	Mitsubishi *(now own Bombardier CRJ series)*	MRJ70	2022	Yes	46.3		69					Mitsubishi Wiki, 2019.
		MRJ90	2020	Yes	47.3	72	88	3,770	35.8			
		MRJ100	2020	Yes		76	100	3,540	34.5			
	Sukhoi	Superjet 100	2007	Yes	62.37	87	108	4,578	29.94			Sukhoi Wiki, 2019.
	Yakovlev	Yak-40	1967	No			32	1,800	20.36			Yakovlev Wiki, 2019a.
Summary data (mean value):					**$48.60M**	**81**	**90**	**3,234**	**29.49**			
Narrow Body	Airbus *(ex Bombardier C series)*	A220-100	2016	Yes	86.04	116	135	6,300	35			Airbus, 2019d; A220 Wiki, 2019.
		A220-300	2016	Yes	97.19	141	160	6,200	38.7			
	Airbus	A318	2003	Yes	107.49	107	136	5,750	31.44			A318 wiki, 2019; Airbus, 2019a;
		A319	1993	No		134	160	6,945	33.84			A319 wiki, (2019); Airbus, 2019e.
		A319LR	1994	Yes	154.39	150	160	6,940	33.84			
		A319neo	2019	Yes	92.3	120	160	6,850	33.84			
		ACJ319neo	1994	Yes	180.93	120	160	6,850	33.84			Airbus, 2019e.
		ACJ320neo	2016	Yes	122.15	150	180	6,300	37.57	500,000	1,200,000	Airbus, 2019f.
		A320	1996	Yes	165.31	150	195	6,112	37.57			A320 Wiki, 2019.
		A321	1996	Yes		185	230	5,926	44.51			A321 Wiki, 2019.

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
		A321-100	1992	Yes		185	236	5,930	44.51			
		A321-200	1996	Yes		185	236	5,930	44.51			
		A321LR	2018	Yes	120.56	185	236	5,930	44.51			
		A321XLR	2021	Yes		206	240	7,410	44.51			
		ACJ321neo	2017	Yes	123.10	180	220	7,800	44.51			Airbus, 2019g.
	Boeing	717-200	1998	No		191	134	3,815	37.8			Boeing, 2013; Boeing, 2014; Boeing, 2019b; Boeing, 2019n; Boeing, 2019o; Boeing, 2019p; Boeing, 2019q; Boeing, 2019r.
		737-100 (original)	1967	No		185	203	2,850	29			
		737-200 (original)	1967	No		203	217	4,800	30.53			
		737-300 (classic)	1984	No			266	3,815	31			
		737-400 (classic)	1988	No		306	315	4,398	31			
		737-500 (classic)	1989	No		232	242	4,398	42			
		737-600 (next gen)	1998	No	138.78	231	238	5,991	31.24	400,000	600,000	
		737-700 (next gen)	1997	Yes			268	5,570	33.63	400,000	600,000	
		737-800 (next gen)	1997	Yes	168.07		335	5,436	39.47	400,000	600,000	
		737-900 (next gen)	2000	Yes	168.09	354	392	5,460	42.11	400,000	600,000	
		737-900ER (next gen)	2006	Yes	143.74	178	392	5,460	42.11	400,000	600,000	
		737-MAX 7	2016	Yes			291	6,110	35.56		600,000	
		737-MAX 8	2016	Yes			340	6,110	35.56		600,000	
		737-MAX 9	2016	Yes			371	7,130	43.8		600,000	
		737-MAX 10	2016	Yes			392	7,130	43.8		600,000	
		757-200	1981	No	189.23	200	239	7,250	47.3		400,000	Boeing, 2013; Boeing, 2019x.
		757-300	1981	No	232.89	243	295	6,295	54.4			
	Comac	C919	2019	Yes		158	168	4,075	38.9			Comac Wiki, 2019a.
		C919ER	2019	Yes		158	168	5,555	38.9			
		ARJ21-700	2016	Yes	42.49	70	95	3,700	33.46			Comac Wiki, 2019b.
		ARJ21-900	2016	Yes	42.49	95	105	3,300	36.35			
	Embraer	E170	2004	Yes	55.89	66	78	3,982	29.9			Embraer Wiki, 2019c; Embraer Wiki, 2019d.
		E175	2005	Yes	60.33	76	88	4,074	31.68			
		E175-E2	2018	Yes	46.8	120	146	3,735	31			
		E190	2005	Yes	66.80	100	124	4,537	36.24			
		E190-E2	2018	Yes	54.62	96	114	5,280	36.24			
		E195	2005	Yes	70.63	100	124	4,260	38.65			
		E195-E2	2018	Yes	61.55	120	146	4,800	41.5			
	Fokker	100	1986	No		97	122	3,170	35.53			Fokker Wiki, 2019b.

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
	Irkut	MC-21-200	2021	Yes	72	132	165	6,400	36.8			Irkut Wiki, 2019.
		MC-21-300	2021	Yes	91	163	211	6,000	42.2			
	McDonnell Douglas	DC9-15	1965	No	41.87	90	109	2,800	31.82			McDonnell Douglas Wiki, 2019a; McDonnell Douglas Wiki, 2019b; McDonnell Douglas Wiki, 2019c.
		DC9-32	1965	No	41.87	115	127	2,800	36.36			
		DC9-41	1965	No	41.87	125	128	2,200	38.28			
		DC9-51	1965	No	41.87	135	139	2,400	40.72			
		MD-88/81/83/88	1979	No	155.38	143	172	4,720	45.06			
		MD-87	1979	No	155.38	117	139	5,400	39.75			
		MD-90	1999	No	74.34	141	172	4,143	46.51			
	Tupolev	TU-154B-2	1972	No		114	180	2,500	48			Tupolev Wiki, 2019a; Tupolev Wiki, 2019b; Tupolev Wiki, 2019c.
		TU-154M	1972	No		114	180	5,280	48			
		TU-204-100	1996	Yes	57.28	172	210	4,300	41.8			
		TU-204-120	1996	Yes	57.28	172	210	4,100	41.8			
		TU-204-214	1996	Yes	57.28	180	210	4,340	41.8			
		TU-204-300	1996	Yes	57.28	142	156	5,800	40.19			
		TU-204SM	1996	Yes	57.28	176	215	4,200	46.14			
		TU-334	1999	No	67.45		102	3,150	31.26			
	Yakovlev	Yak-42	1973	No		102	120	4,000	33.38			Yakovlev Wiki, 2019b.
				Summary data (mean value):	**$96.53M**	**152**	**197**	**5,067**	**38.57**	**416,666**	**636,363**	
Wide body	Airbus	A300B4-200	1974	No	570.98	281	345	5,375	53.61			A300 Wiki, 2019; A340 Wiki, 2019; A350 Wiki, 2019; A380 Wiki, 2019; Airbus, 2019i; Airbus, 2019j; Airbus, 2019k; Airbus, 2019l; CNN Travel, 2018.
		A300-600R	1983	No	270.28	247	345	7,500	64.08			
		A310				190	230	8,060	46.66			
		A330-200	1992	Yes	434.51	210	406	13,450	58.82			
		A330-300	2013	Yes	289.09	250	440	11,750	63.66			
		A330-800	2015	Yes		220	406	15,100	58.82			
		A330neo-800	2015	Yes	278.08	220	406	15,100	58.82			
		A330neo-900	2015	Yes	317.13	260	440	13,400	63.66			
		A340-200	1993	No	338.70	210	420	12,400	59.4	1,200,000	3,000,000	
		A340-300	1993	No	478.92	250	290	13,500	63.69	1,200,000	3,000,000	
		A340-500	1991	No	558.61	270	310	16,670	67.93	1,200,000	3,000,000	
		A340-600	1997	No	495.81	320	475	14,450	75.36	1,200,000	3,000,000	
		A350-900	2014	Yes	342.17	315	400	15,000	66.8			
		A350-1000	2014	Yes	395.10	369	480	16,100	73.8			
		A380	2003	No	445.6	555	868	14,800	72.72		4,000,000	

Type	Maker	Model #	Made from	Made in 2019?	2019 Cost ($ M)	Seats (min)	Seats (max)	Range (km)	Length (m)	Part data (Min)	Part data (Max)	Source(s)
	Boeing	747SP	1971	No		194	400	10,800	56.3			747 Wiki, 2019; Boeing, 2013; Boeing, 2019s; Lufthansa. 2019.
		747-100	1968	No	146.7	366	440	8,560	70.66			
		747-200	1976	No	793.08	366	550	12,150	70.66			
		747-300	1982	No	587.72	416	550	14,200	70.66			
		747-400	1998	N0	415.09	416	660	13,490	70.66		6,000,000	
		747-400ER	1998	No	318.77	416	660	14,045	70.66		6,000,000	
		747-8	2008	Yes	499.99	467	605	7,730	76.3		6,000,000	
		767-200ER	1978	No		174	290	12,200	86.9		3,100,000	Boeing, 2013; Boeing, 2019t;
		767-300ER	1995	No	365.69	210	351	11,070	114.1		3,100,000	
		767-400ER	2000	No		245	375	10,415	138.9		3,100,000	
		777-200	1994	No		305	440	9,700	63.73		3,000,000	Boeing, 2013; Boeing, 2019m; Boeing, 2019u; Boeing, 2019v; Boeing, 2019w; Swiss, 2019.
		777-200ER	1997	No	485.67	305	440	13,080	63.73		3,000,000	
		777-200LR	2006	Yes	442.56	301	440	9,200	63.73		3,000,000	
		777-300	1995	No		368	550	11,121	73.86		3,000,000	
		777-300ER	2016	Yes	398.85	368	550	13,650	73.86		3,000,000	
		777-8 (777x)	2017	Yes	426.85		384	16,170	69.79			
		777-9 (777x)	2017	Yes	460.15	414	426	13,500	76.72			
		787-8	2011	Yes	283.61	242	381	13,621	56.72		2,300,000	Boeing, 2013; Boeing, 2019i; Boeing, 2019m.
		787-9	2010	Yes	340.29	262	420	7,530	62.81		2,300,000	
		787-10	2013	Yes	370.28	298	440	6,345	58.28		2,300,000	
	Craic	CR929	2027	Yes		261	440	12,000	63.75			Craic Wiki, 2019.
	Ilyushin	II-86	1980	No		320	350	5,000	60.21			Ilyushin Wiki, 2019a; Ilyushin Wiki, 2019b.
		II-96-300	1992	Yes	161.22	237	300	11,500	55.3			
		II-96M	1997	Yes		307	420	12,800	64.7			
		II-96-400	2019	Yes		215	436	10,000	63.93			
	Lockheed	Tristar L-1011-1	1975	No	595.75	256	400	2,680	54.17			Lockheed Wiki, 2019k.
		Tristar L-1011-200	1977	No	531.26	256	400	3,600	54.17			
		Tristar L-1011-500	1979	No	456.71	246	300	5,345	50.05			
	McDonnell Douglas	DC-10-10	1970	No	813.01	270	399	6,500	55.55			McDonnell Douglas Wiki, 2019d.
		DC-10-30	1984	No	302.57	270	399	9,600	55.35			
		DC-10-40	1973	No	721.19	270	399	9,400	55.54			
Summary data (mean value):					**$432.34M**	**294**	**432**	**11,079**	**66.73**	**1,200,000**	**3,431,579**	

Appendix 2: Data Model: Substance Level Data Tables

Appendix 2: Substance Level Data Tables

Table name	Data field	Description	Function(s)
SubstanceAnalysis – Substance level data related to specifications and standards maintained jointly between HSE and Materials functions.	SUBAID	Substance analysis unique ID number.	HSE, Materials.
	MixtureID	Mixture unique reference number.	
	MaterialID	Material unique reference number.	
	SpecSDSID	Specification / Safety Data Sheet reference ID.	
	DefinedBy	Source of definition (Internal – Material, Internal – Mixture, Supplier Defined, Customer Defined, Industry Standard, Military Standard).	
	Name	Name of mixture or material.	
	UsageDescription	Use description of mixture or material (*if available*).	
	Manufacturer	Manufacturer of chemical substance, mixture, or material.	
	CountryOfOrigin	As displayed on product labelling.	
	PublicationDate	Date from SDS, eSDS, MSDS or TDS.	
	Status	Status of chemical substance, mixture, or material (*Current, Legacy, DO NOT USE*).	
	SDSUFICode	EU Poison Centre Notification number for a registered formulation containing a hazardous substance, from January 2021.	
	SDSUKCode	UK REACH registered SDS data, from January 2021.	
	QtySupplied	Supplied volume	
	UoM	Unit of Measure (*mg, g, kg, ml, ltr*).	
	QtyUsed	Amount of chemical substance, mixture or material consumed.	
	QtyGramWeight	Gram weight of chemical substance, mixture or material consumed.	
	MandatoryOptional	Identification of chemical substance defined within a specification or standard (*Mandatory, Optional*).	
	SUGID	Safe use guidance ID number as applicable to chemical substance.	
	SubstanceName	Name of chemical substance.	
	CAS	CAS number of chemical substance.	
	EC	EC number of chemical substance.	
	Min	Min amount of chemical as defined in SDS, MSDS, specification or standard.	
	QtyMixMin	Min value based as percentage of QtyGramWeight.	
	MinTon	Min gram weight converted as Ton weight per article.	
	SumMinTon	Sum MinTon value multiplied by article quantity.	
	Max	Max amount of chemical as defined in SDS, MSDS, specification or standard.	
	QtyMixMax	Max value based as percentage of QtyGramWeight per article.	
	SumMaxTon	Sum MaxTon value multiplied by article quantity.	

Table name	Data field	Description	Function(s)
	MaxTon	Max gram weight converted as Ton weight.	
	SDSAssessment	SDS assessment by HSE function (Awaiting assessment of substance within SDS, Awaiting assessment of substance within Specification, Awaiting assessment of substance, SDS substance assessed safe use guidance created, SDS substance assessed awaiting safe use guidance).	
	HSEReviewedBy	HSE function employee who performed HSE review.	
	HSEReviewDate	HSE review date.	
	HSEComments	Any additional HSE function review comments.	
	MaterialsAssessment	Materials function assessment (Substance awaiting review, Substance is not declarable above 0.1% w/w, Substance is declarable above 0.1% w/w, Further analysis required, Low Priority - Legacy Mixture, Obsolete DO NOT USE).	
	MATReviewedBy	Materials function employee who performed review.	
	MATReviewedDate	Materials function review date.	
	MATComments	Any additional materials function review comments.	
Mixture – Details of internally defined mixtures.	MixtureID	Mixture unique reference number.	Materials
	SUBAID	Substance Analysis ID (from SubstanceAnalysis table).	
	Name	Name of mixture.	
	UsageDescription	Use description of mixture (*if available*).	
	UsageQty	Qty used.	
	ReviewStatus	Mixture review status (Awaiting review, Reviewed - More Data Needed from Manufacturer, Reviewed - More Data Requested from Manufacturer, Reviewed - Current Mixture, Reviewed - Legacy Mixture, Low Priority – Legacy Mixture).	
	ReviewedBy	Mixture reviewed by.	
	ReviewedDate	Mixture review date.	
	Comments	Any additional comments.	
Material – Details of internally defined materials.	MaterialID	Material unique reference number.	Materials
	SUBAID	Substance Analysis ID (from SubstanceAnalysis table).	
	Name	Name of material.	
	UsageDescription	Use description of material (*if available*).	
	UsageQty	Qty used.	
	ReviewStatus	Material review status (Awaiting review, Reviewed - More Data Needed from Manufacturer, Reviewed - More Data Requested from Manufacturer, Reviewed - Current Material, Reviewed - Legacy Material, Low Priority – Legacy Material).	
	ReviewedBy	Material reviewed by.	
	ReviewedDate	Material review date.	
	Comments	Any additional comments.	
	DSLID	DSL record unique ID number.	

Table name	Data field	Description	Function(s)
DSLReference – *DSL index*.	Name	Short reference name for a DSL.	Regulatory Compliance.
	Description	Long DSL name.	
	Date	Date created / updated.	
	Comments	Additional comments.	
DetailedDSL – Detailed substances defined to a given DSL.	DSLID	DSL record unique ID number (refers to DSLReference DSLID number).	Regulatory Compliance.
	SubstanceName	Name of chemical substance.	
	Description	Long DSL name.	
	DSLReference	Additional grouping information relating to chemical substance within a DSL.	
	CAS	CAS number.	
	EC	EC number.	
	ReportableThreshold	Threshold level for substance as defined by a DSL.	
	DSLSubstanceComments	Additional comments.	
SafeUseGuidance – Safe use information in the content of a chemical substance.	SUGID	DSL record unique ID number (refers to DSLReference DSLID number).	HSE, Materials.
	SubstanceName	Name of chemical substance.	
	CAS	CAS number.	
	EC	EC number.	
	EchaHazardClass	Hazard classification taken from searching the **ECHA website information on chemicals page**.	
	ChemicalUseData	Details of stability of the chemical and any exposure scenario information.	
	ToxicologicalData	Toxicological data in line with the chemical substance data on **ECHA website information on chemicals page**.	
	AssemblyDisassembly	Details of and Personal Protective Equipment (PPE) to be used when using the chemical substance in a assembling or disassembling articles.	
	MechanicalRemoval	Details of any mechanical removal of the chemical substance from an article.	
	ChemicalRemoval	Details of any chemical removal of the chemical substance from an article.	
	EngineeringControls	Details of any localised engineering controls when handling the chemical substance.	
	PersonalProtectiveEquipment	Additional PPE data.	
	DisposalConsiderations	Details of any disposal considerations in relation to the chemical substance.	
	ECHAReference	Unique URL for the chemical substance as obtained from **ECHA website information on chemicals page**.	
	AdditionalReference	Any additional references to the chemical substance in relation to aerospace uses of the chemical substance.	
	Status	Status (Awaiting Review, Reviewed Safe Use Guidance Created, On Hold Awaiting Further Information).	
	ReviewedBy	Safe Use Guidance data reviewed by.	
	ReviewedDate	Safe Use Guidance data review date.	
	Comments	Any additional comments.	
MasterChemical InventoryList – Audit of chemical substances,	InvID	Unique chemical substance inventory ID number.	Stores.
	SUBAID	Substance Analysis ID (from SubstanceAnalysis table).	
	TradeProductName	Commercial trade name for a chemical substance, mixture or material as shown on product label.	

Table name	Data field	Description	Function(s)
mixtures and materials physically held in stock across manufacturing locations.	Year	Year of manufacture shown on product label.	
	Manufacturer	Name of manufacturer shown on product label.	
	CountryofOrigin	Country of origin / manufacture shown on product label.	
	WhereFound	Identification of manufacturing cell where the chemical substance, mixture or material was identified.	
	StorageLocation	Storage location within manufacturing cell where the chemical substance, mixture or material was identified.	
	AlternativeName	Local alternative names for the chemical substance, mixture, or material.	
	AuditedBy	Chemical substance inventory data reviewed by.	
	AuditDate	Chemical substance inventory data review date.	

Appendix 3: Data Model: Article Level Data Tables

Appendix 3: Article Level Data Tables

Table name	Data field	Description	Function(s)
Component / PartNumber / Assembly – *Individual article specific tables*.	BOMLevel	BOM level (*if applicable*).	Manufacturing.
	Number	Article number.	
	Name	Article description / name.	
	AirFrameLocation	Location of article on aircraft.	
	Classification	Classification of article (Critical, Life Limited Part, Non-Critical or Unknown).	
	Status	Article status (WIP, Pre-Released, Released or Obsolete).	
	Qty	Amount of component, part number or assemblies.	
	ParentNumber	Higher level article where used (*if applicable*).	
	DrawingID	Drawing reference number.	
	SpecSDSID	Specification / Safety Data Sheet reference ID.	
	EngineeringID	Engineering task references.	
	EUTaricCode	EU tariff code for article (*if available*).	
	SCIPNumber	ECHA SCIP submission number (*if available*).	
	MakeBuy	Internally manufactured (make) or sourced from the supply chain (buy), or N/A.	
	BOMType	Engineering-BOM, Manufacturing-BOM, Service-BOM, Customer-BOM, Supplier-BOM or N/A	
	ReviewStatus	Article review status (Awaiting Review, Reviewed, Obsolete).	
	ReviewedBy	Article data reviewed by.	
	ReviewedDate	Article data review date.	
	Comments	Any additional comments.	

Table name	Data field	Description	Function(s)
Drawing – Engineering design system geometry drawings related to articles.	DrawingID	Drawing reference number.	Design.
	DrawingNumber	Drawing number as it appears in source engineering design system.	
	DrawingDate	Drawing date as it appears in source engineering design system.	
	ClassificationMarking	Drawing classification as it appears in source engineering design system (*Uncontrolled, Confidential, Secret, Top-Secret, N/A*).	
	ExportControl	Export Control classification as it appears in source engineering design system (*Yes, No, N/A*).	
	GeometryFileID	Geometry File ID as it appears in source engineering design system.	
	GeometryFileLocation	Location of Geometry file on applicable engineering design system (*Legacy Unix, Legacy PDM, PLM, Unknown*).	
	SpecSDSID	Specification / Safety Data Sheet reference ID.	
	Status	Status of SpecSDSID (WIP, Pre-Released, Released or Obsolete).	
	ReviewStatus	Drawing review status (Drawing awaiting review, Drawing reviewed)	
	ReviewedBy	Drawing reviewed by.	
	ReviewedDate	Drawing review date.	
	Comments	Any additional comments.	
Engineering – Manufacturing task steps.	EngineeringID	Engineering record unique ID number.	Engineering.
	ManufacturingStep	Description of step.	
	ManufacturingTask	Description of task.	
	MachineProgram	Reference to any machine program(s).	
	InspectionTask	Reference to any inspection task(s).	
	TestProcedure	Reference to any testing procedure(s).	
	ReviewStatus	Review status for engineering record (Awaiting Review, Reviewed – Current Process, Reviewed - On-Hold Updates Required, Reviewed - Obsolete Task).	
	ReviewedBy	Engineering function employee who performed review.	
	ReviewDate	Date of review.	
	Comments	Any additional comments.	

Appendix 4: Data Model: Supplier Level Data Tables

Appendix 4: Supplier Level Data Tables

Table name	Data field	Description	Function(s)
Stores – Records of chemical substances, mixtures,	StoresID	Stores unique record ID number.	Stores.
	Number	Internal article number.	
	Name	Internal article description / name.	
	SupplierID	Unique SupplierID number (references from SupplierList table to multiple others).	

Table name	Data field	Description	Function(s)
materials, and articles held in stores warehouse.	SupplierPartNumber	Supplier article number.	
	SupplierPartName	Supplier article description / name.	
	Manufacturer	Supplier article manufacturer name (*if applicable*).	
	CountryOfOrigin	Supplier article country of origin.	
	YearOfManufacture	Supplier article year of manufacture.	
	SpecSDSID	Supplier referenced specification / standard / SDS.	
	SUGID	Safe Use Guidance ID (*if applicable*).	
	UoM	Unit of Measure.	
	UoMValue	Supplier article UoM value.	
	StockLevel	Current stores stock level value.	
	Status	Review status (Awaiting Review, Initial Review – Check Data, Reviewed).	
	ReviewedBy	Article data reviewed by.	
	ReviewedDate	Article data review date.	
	Comments	Any additional comments.	
PurchasingForwardLoad – Supplier future purchase orders.	PurchaseOrderID	Unique purchase order ID number (*defined by purchasing function*).	Purchasing.
	SupplierID	Unique SupplierID number (references from SupplierList table to multiple others).	
	PurchaseOrderRaisedBy	Purchasing function member who raised purchase order.	
	PurchaseOrderDate	Date on which purchase order raised.	
	LeadTime	Expected lead time for article as defined by purchasing function.	
	ScheduledDeliveryDate	Expected delivery date of supplier article based on date ordered and workdays added (*based on LeadTime days*).	
	CustomerOrderID	Referenced demand to originating customer order ID number.	
	CustomerDeliveryDate	Anticipated customer delivery (assumed to be + number workdays added to ScheduledDeliveryDate date, varying on type of order aircraft, spare part or consumable).	
	TargetSchedule	Calculation of workdays between ScheduledDeliveryDate and CustomerDeliveryDate, varying between articles.	
	InternalPartNumber	Internal article number.	
	InternalPartDescription	Internal article description.	
	Type	Internal article number type (Aircraft, Assembly, Part Number, Component, Customer Requirement).	
	OrderQty	Amount of articles ordered on purchase order.	
	Classification	Classification of article (Critical, Life Limited Part, Non-Critical or Unknown).	
	Comments	Additional comments.	
SupplierList – List of suppliers.	SupplierID	Unique supplier ID number.	Purchasing, Regulatory Compliance.
	SupplierName	Supplier name.	
	DUNSCode	Dun and Bradstreet assessment code for supplier organisation.	
	CAGECode	Commercial and Government Entity Code, or CAGE Code.	
	AddressStreet	Supplier street address.	

Table name	Data field	Description	Function(s)
	AddressCity	Supplier city address.	
	AddressState	Supplier state address.	
	AddressCountry	Supplier country address.	
	AddressZIP	Supplier ZIP / postal code.	
	ProductType	Supplier classification by product type.	
	SupplierPhonePublic	Supplier publicly available phone number.	
	SupplierWebsitePublic	Supplier publicly available phone website.	
	Comments	Additional comments.	
SupplierGDPR – GDPR protected table.	SupplierContactID	Supplier contact unique ID number.	Purchasing, Regulatory Compliance.
	SupplierID	Unique supplier ID number.	
	ContactName	Supplier contact unique name.	
	ContactEmail	Supplier contact name.	
	AddressStreet	Supplier contact street address.	
	AddressCity	Supplier contact city address.	
	AddressState	Supplier contact state address.	
	AddressCountry	Supplier contact country address.	
	AddressZIP	Supplier contact ZIP / postal code.	
	Comments	Additional comments.	
RequestorGDPR – GDPR protected table.	RequestorID	Requestor unique ID number	Regulatory Compliance.
	ContactName	Requestor contact unique name.	
	ContactEmail	Requestor contact name.	
	AddressStreet	Requestor contact street address.	
	AddressCity	Requestor contact city address.	
	AddressState	Requestor contact state address.	
	AddressCountry	Requestor contact country address.	
	AddressZIP	Requestor contact ZIP / postal code.	
	Comments	Additional comments.	
SupplierDeclaration – Declaration tracking information.	DeclarationID	Unique supplier declaration ID number.	Regulatory Compliance.
	SupplierID	Unique supplier ID number (*from SupplierGDPR*).	
	ContactName	Suppliers contact unique name (*from SupplierGDPR*).	
	SupplierDeclarationStatus	Declaration status.	
	RequestorID	Regulatory compliance member making supplier declaration request.	
	RequestedDate	Date of supplier declaration request.	
	RequestorComments	Requestor comments (internal)	
	TermsConditions	Any terms and conditions	

Table name	Data field	Description	Function(s)
	ReportableSubstanceList	Regulatory Substance List report against (EU REACH, IAEG AD-DSL, EU RoHS, Full Material Declaration, Unknown).	
	DeclarationDetailID	Detailed declaration ID number (*from DetailedDeclaration*).	
	DeclarationComments	Additional comments from Regulatory Compliance function.	
DetailedDeclaration – Detailed declaration data.	DeclarationDetailID	Detailed declaration ID number.	Regulatory Compliance and Supplier(s).
	DeclarationType	Declaration reporting format type (EU REACH, IAEG AD-DSL, EU RoHS, Full Material Declaration, Unknown).	
	SupplierContactID	Supplier contact unique ID number (*from SupplierGDPR*).	
	ReceivedDate	Date declaration received from supplier.	
	Number	Internal article number.	
	Name	Internal article name.	
	Description	Additional article information.	
	BOMLevel	Details of the article in a BOM structure.	
	AirFrameLocation	Location of article on the aircraft.	
	SupplierPartNumber	Supplier article number.	
	SupplierPartName	Supplier article description / name.	
	SupplierPartVersion	Supplier part revision indicator (*if applicable*).	
	SupplierUoM	Supplier UoM (*g, kg,*).	
	SupplierPartWeight	Supplier part weight.	
	CountryOfOrigin	Supplier article country of origin.	
	EUTaricCode	EU tariff code for article (*if available*).	
	SCIPNumber	ECHA SCIP submission number (*if available*).	
	SafeUseGuidance	Supplier provided safe use guidance.	
	NoSupplied	Article quantity supplied	
	SpecSDSID	Supplier referenced specification / standard / SDS.	
	MaterialMixtureName	Name of mixture or material where a substance of concern appears.	
	Manufacturer	Mixture or material manufacturer name (*if applicable*).	
	UoM	Unit of Measure (*mg, g, kg, ml, ltr*).	
	QtyUsed	Amount of mixture or material consumed.	
	QtyGramWeight	Calculation of UoM and QtyUsed into a gram weight value.	
	SubstanceName	Name of chemical substance.	
	CAS	CAS number of chemical substance.	
	EC	EC number of chemical substance.	
	Min	Min amount of chemical as defined in SDS, MSDS, specification or standard.	
	QtyMixMin	Min value based as percentage of QtyGramWeight.	
	MinTon	Min gram weight converted as Ton weight per article.	

Table name	Data field	Description	Function(s)
	SumMinTon	Sum MinTon value multiplied by article quantity.	
	Max	Max amount of chemical as defined in SDS, MSDS, specification or standard.	
	QtyMixMax	Max value based as percentage of QtyGramWeight per article.	
	SumMaxTon	Sum MaxTon value multiplied by article quantity.	
	MaxTon	Max gram weight converted as Ton weight.	
	UseDescription	Description of chemical substance use.	
	ProcessChemical	Identification of chemical substance being a process chemical which does appear on the finished article.	
	Article Flag	Indication of the reported item being an article.	
	Attachment	Link to any additional supporting documentation	
	RoHSExemption	Details of any EU RoHS exemptions utilised by the supplier.	
	REACHAuthorisation	Details of any EU REACH Authorisations utilised by the supplier.	
PositiveDeclaration – Sent to a supplier for further clarification once a substance of concern has been identified.	PositiveDeclarationID	Positive declaration unique ID number.	Regulatory Compliance and Supplier(s).
	DeclarationDetailID	Original supplier declaration ID (*from DetailedDeclaration*).	
	ReceivedDate	Date original detailed declaration received.	
	SupplierContactID	Supplier contact ID number.	
	Status	Positive declaration status (Positive Declaration Requested, Positive Declaration Received, On-Hold Awaiting Further Information, Positive Declaration Completed).	
	PosDateRequested	Date positive declaration requested from supplier.	
	PosDateReceived	Date positive declaration received from supplier.	
	Number	Internal article number.	
	Name	Internal article name.	
	SupplierName	Article supplier name.	
	SupplierPartNumber	Supplier article number.	
	SupplierPartName	Supplier article description / name.	
	SupplierPartWeight	Supplier article weight.	
	CountryofManufacture	Supplier article country of origin.	
	EUTaricCode	EU tariff code for article (*if available*).	
	SCIPNumber	ECHA SCIP submission number (*if available*).	
	SubstanceName	Name of chemical substance.	
	CAS	CAS number of chemical substance.	
	EC	EC number of chemical substance.	
	ConcOrigDeclared	Substance originally declared concentration value.	
	SupplierConfirmed	Concentration range as defined in ECHA SCIP reporting requirements (>0.1% w/w and <0.3% w/w, >0.3% w/w and <1% w/w, >1% w/w and <10% w/w, >10% w/w and <20% w/w, >20% w/w/ and <100% w/w, >0.1% w/w and <100% w/w).	

Table name	Data field	Description	Function(s)
	ProductionInEU	Required EU SCIP reporting field (EU Produced, EU Imported, EU Produced and Imported, No Data).	
	ProcessChemical	Identification of chemical substance being a process chemical which does appear on the finished article (*Yes, No*).	
	InMaterialForm	Substance appears on affected article in a material form, required for EU SCIP reporting (*Yes, No*).	
	EUMatCat	EU material category code as defined for EU SCIP reporting.	
	InMixtureForm	Substance appears on affected article in a mixture form, required for EU SCIP reporting (*Yes, No*).	
	EUMixCat	EU mixture category code as defined for EU SCIP reporting.	
	ListRegulation	Supplier reconfirmation of regulatory substance list which has been reported against	
	SupplierAwarenessRegulation	Confirmation of supplier regulatory awareness.	
	ExemptionUsed	Confirmation of supplier using any existing EU RoHS exemptions.	
	ExemptionSought	Confirmation of supplier seeking any EU RoHS exemptions.	
	ExemptionNumber	Details of any EU RoHS exemptions.	
	AuthorizationUsed	Confirmation of supplier using any existing EU REACH Authorisations.	
	AuthorizationSought	Confirmation of supplier seeking any EU REACH Authorisations.	
	AuthorizationNumber	Details of any EU REACH Authorisations.	
	SupplierStrategy	Details of any supplier strategy in relation to the use of a chemical of concern.	
	Comments	Any additional supplier comments in relation to the use of a chemical of concern.	
EUTaricCode – EU codes identifying tariff codes for articles.	TaricID	Unique EU Taric ID number.	Accounting.
	EUTaricCode	EU Taric Code number as defined in the EU SCIP reporting system.	
	AirFrameLocation	General location of an article within aircraft as defined by accounting function in relation to EU TARIC code system (*Air Conditioning, Airframe Structure, Electronics, Miscellaneous, Power Module*).	
	TaricSectionID	EU Taric code section ID.	
	TaricSectionDescription	Description of EU Taric code section	
	Level1 to Level8	Descriptive levels for a given EU Taric code.	
	Source	Source of EU Taric code data.	
	Status	Review status of EU Taric code (Awaiting Review, Tariff Code: Applicable, Tariff Code: Not Applicable, On Hold: Awaiting Further Information).	
	ReviewedBy	Accounting function employee reviewing EU Taric code data.	
	ReviewDate	Date of EU Taric code review.	
MaterialCategory – Define ECHA SCIP material categories.	ECHAID	ECHA defined unique material category ID number.	Regulatory Compliance.
	PhraseText0	Name of material.	
	AdditionalPhraseText	Material broken down into use and applicability.	
MixtureCategory - Define ECHA	ECHAID	ECHA defined unique mixture category ID number.	Regulatory Compliance.
	AircraftUse	Applicability of mixture category to use in a Aircraft. Generated based on MixtureCode, MixtureCategory and MixtureType values	

Table name	Data field	Description	Function(s)
SCIP mixture categories.	MIxtureCategory	ECHA defined values for mixture categories as taken from European Poison Centre notifications.	
	MixtureType	ECHA defined values for mixture types as taken from European Poison Centre notifications	

Appendix 5: Data Model: Customer Level Data Tables

Appendix 5: Customer Level Data Tables

Table name / Description	Data field	Description	Function(s)
SalesGDPR – GDPR protected table.	CustomerID	Unique customer ID number.	Stores
	CustomerName	Customer name.	
	AirportCode	Main airport ICAO code location for customer aircraft.	
	AirportName	Main airport name.	
	ContactID	Customer contact ID number.	
	ContactName	Customer contact name.	
	ContactPhoneNo	Customer contact phone name.	
	ContactEmail	Customer contact email address.	
	AddressStreet	Customer contact street address.	
	AddressState	Customer contact city address.	
	AddressCountry	Customer contact state address.	
	AddressZIP	Customer contact country address.	
	Comments	Additional comments	
SalesForwardLoad – Details of future customer orders that need to be fulfilled.	CustomerID	Unique customer ID number (*from SalesGDPR*).	Sales
	OrderID	Unique sales order ID number.	
	OrderDate	Unique sales order ID number date of order.	
	Number	Article number on order.	
	Name	Article name on order.	
	Type	Article type on order (Assembly, Sub-Assembly, Part Number, Component).	
	Qty	Quantity of article on order.	
	LeadTime	Anticipated lead time for the article on order.	
	ScheduledDeliveryDate	Based on OrderDate + LeadTime calculated in workdays.	
	Comments	Additional comments.	
	TransportID	Unique transport ID number.	Stores

Table name / Description	**Data field**	**Description**	Function(s)
Transport – Articles packaged and dispatch to customers.	OrderID	Unique sales order ID number (*from SalesForwardLoad*).	
	Number	Article number on order (*from SalesForwardLoad*).	
	Name	Article name on order (*from SalesForwardLoad*).	
	Qty	Quantity of article on order (*from SalesForwardLoad*).	
	CustomerID	Unique customer ID number (*from SalesGDPR*).	
	ContactID	Customer contact ID number (*from SalesGDPR*).	
	PackagingID	Packaging ID number (*from Packaging*).	
	TechPubID	Technical publications ID number (*from TechPubs*).	
	DispatchMethod	Dispatch method to customer.	
	DispatchDate	Date of dispatch to customer.	
Packaging – Article packaging types.	PackagingID	Unique packaging ID number.	Stores
	PackagingType	Type of packaging.	
	PackagingMaterial	Packaging material type.	
	PackagingWeight(kg)	Packaging weight (kg)	
TechnicalPublications – Technical documentation in relation to articles.	TechPubID	Unique technical publications ID number.	Technical Publications
	Number	Article number.	
	Name	Article name.	
	Date	Date of initial technical publication creation.	
	ComplianceStatement	Type of compliance statement	
	SubstanceName	Name of chemical substance.	
	CAS	CAS number of chemical substance.	
	EC	EC number of chemical substance.	
	SUGID	Safe Use Guidance ID (*from SafeUseGuidance*).	
	CreatedBy	Technical publication's function employee name.	
	Date	Date of technical publication creation / update.	
	ReviewedBy	Technical publication's function employee name.	
	ReviewDate	Date of technical publication review.	
CustomerDeclarations – Customer material regulations.	DeclarationID	Unique customer declaration ID number.	Regulatory Compliance
	CustomerID	Unique customer ID number (*from SalesGDPR*).	
	CustomerName	Customer name (*from SalesGDPR*).	
	OrderID	Unique sales order ID number (*from SalesForwardLoad*).	
	OrderDate	Unique sales order ID number date of order (*from SalesForwardLoad*).	
	ContactID	Customer contact ID number (*from SalesGDPR*).	
	DeclarationStatement	Type of regulatory customer declaration.	

Table name / Description	**Data field**	**Description**	Function(s)
	Type	Article type (Assembly, Sub-Assembly, Part Number, Component).	
	Number	Article number.	
	Name	Article name.	
	AirFrameLocation	General location of an article within aircraft.	
	EUTaricCode	EU tariff code for article (*if available*).	
	SCIPNumber	ECHA SCIP submission number (*if available*).	
	ProductionInEU	Required EU SCIP reporting field (EU Produced, EU Imported, EU Produced and Imported, No Data).	
	SubstanceName	Name of chemical substance.	
	CAS	CAS number of chemical substance.	
	EC	EC number of chemical substance.	
	Concentration	Concentration range as defined in ECHA SCIP reporting requirements (>0.1% w/w and <0.3% w/w, >0.3% w/w and <1% w/w, >1% w/w and <10% w/w, >10% w/w and <20% w/w, >20% w/w/ and <100% w/w, >0.1% w/w and <100% w/w).	
	DataSource	Data source for the declared data.	
	RegulationListName	Regulatory substance list against which the data is being reported.	
	RegulationListDate	Date of the Regulatory substance list.	
	SUGID	Safe use guidance ID number (*from SafeUseGuidance*).	
	ReviewedBy	Regulatory compliance function employee who created the customer declaration.	
	ReviewDate	Date customer declaration generated.	
	Comments	Additional comments.	
AirWorthiness – Air worthiness data for articles that are defined as being Critical or Life Limited Parts.	AWID	Air worthiness unique ID number.	Air Worthiness
	CustomerID	Unique customer ID number (*from SalesGDPR*).	
	Number	Article number.	
	Name	Article name.	
	AirFrameLocation	General location of an article within aircraft.	
	Type	Article type (Assembly, Sub-Assembly, Part Number, Component).	
	Classification	Classification of article (Critical, Life Limited Part, Non-Critical or Unknown).	
	Status	Article status (WIP, Pre-Released, Released or Obsolete).	
	SerialOriginal	Original article serial number	
	CurrentSerial	Current article serial number following any repair and refurbishment activities.	
	TypeApproval	Article air regulator approval type need (Awaiting Approval, CAA, FAA, EASA, CAA+EASA, FAA+EASA, CAA+FAA+EASA, Not Applicable).	
	OriginalCertDate	Original article certification date.	
	LastUpdateBy	Airworthiness function employee who performed update to record.	
	LastUpdateDate	Last update date.	

Table name / Description	**Data field**	**Description**	Function(s)
MRO – Maintenance, Repair and Overhaul activities detailing repair schemes and repair tasks.	MROID	MRO unique ID number.	MRO
	RepairScheme	Repair scheme number.	
	RepairTask	Repair task details.	
	MandatoryOptional	Applicability of repair task (*Mandatory*, *Optional*).	
	SpecSDSID	Referenced specification / standard / SDS.	
	RepairApprover	Details of any air worthiness approvals needed (Awaiting Action, Not Required, Seek Airworthiness Approval, Airworthiness Approval Defined).	
	RepairSchemeApproval	(Awaiting Approval, CAA, FAA, EASA, CAA+EASA, FAA+EASA, CAA+FAA+EASA, Not Applicable).	
	ReviewStatus	Repair task status (Awaiting Review, Reviewed Current, Reviewed Legacy, Review On Hold).	
	ReviewedBy	MRO function employee who performed data creation / update.	
	ReviewDate	Date of MRO task creation / update.	
	Comments	Additional comments.	

Appendix 6: Data Model: *Other Tables*

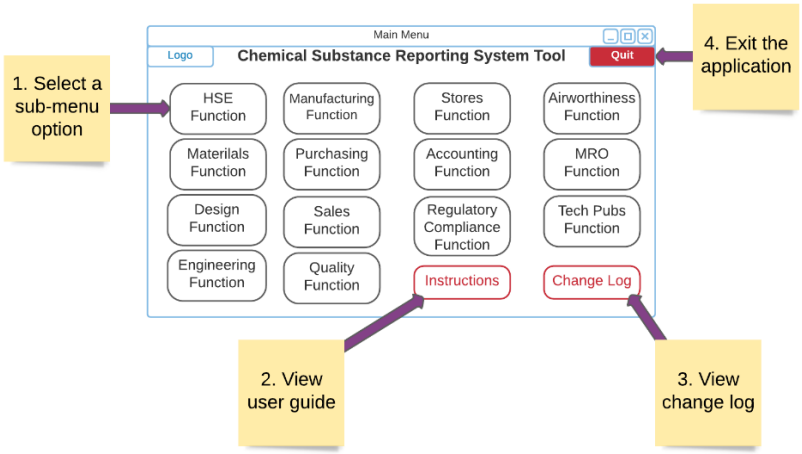
Appendix 6: Other Tables

Table name / Description	**Data field**	**Description**	Function(s)
Quality – Companywide or specific function quality processes and procedures	QProcID	Unique procedure / process ID number.	Quality
	Name	Name of quality procedure / process.	
	Details	Details of quality procedure / process.	
	ApplicableBusinessFunctions	Companywide or specific business name.	
	Templates	Applicable database table(s) which need to be maintained and imported into application.	
	Status	Quality procedure / process status (Awaiting Review, Reviewed – Valid, Reviewed – Obsolete, Reviewed - On Hold).	
	ReviewedBy	Quality function employee who performed data creation / update.	
	ReviewDate	Date of procedure / process creation / update.	
	CrossReferenceStandard	Details of any cross-referenced international standard(s).	
ChangeLog – Records changes to the application.	VersionID	Application change ID number.	Regulatory Compliance
	Date	Date of application change.	
	Details	Details of application change.	

Appendix 7: Application UI Storyboards

MainMenu UI

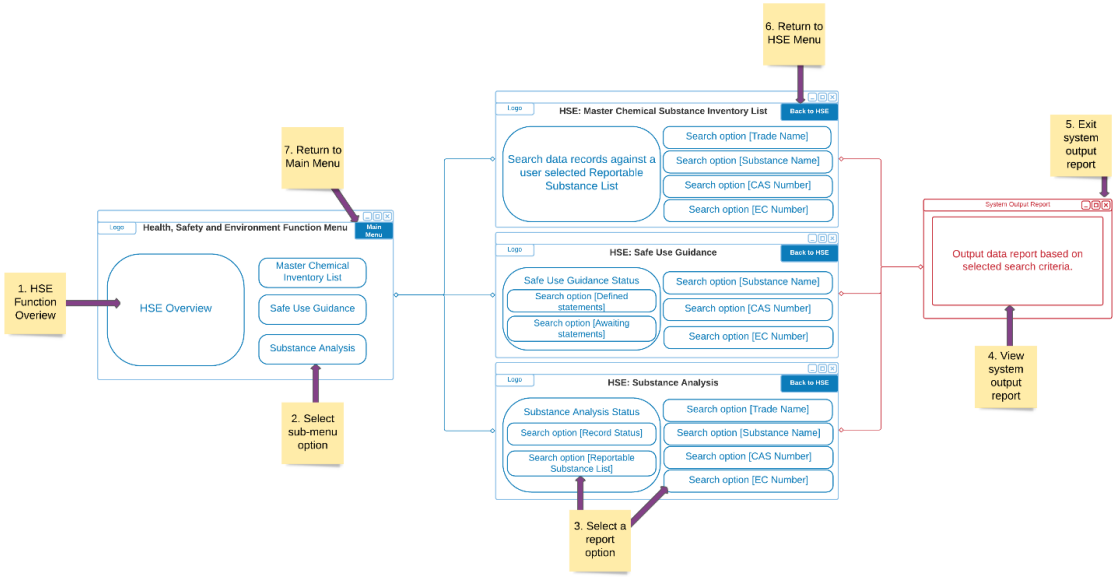
The application is launched by the user double-clicking on the application name. Once launched a simple MainMenu UI is presented, as shown in Figure [Appendix Figure 1]. The aim of the MainMenu UI is to present the user with navigation buttons to the functional area sub-menus which allow for viewing of data imported into the application.



Appendix Figure 1: MainMenu UI

HSE Function UI

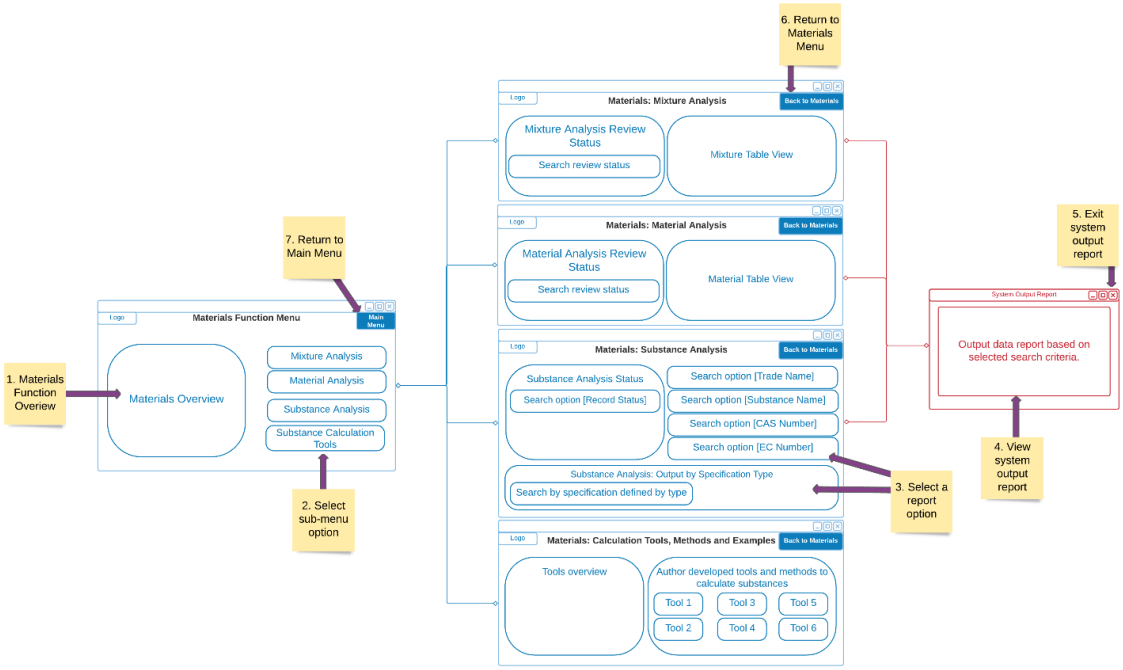
The HSE function menu options are shown in Figure [Appendix Figure 2].



Appendix Figure 2: HSE Function UI

Materials Function UI

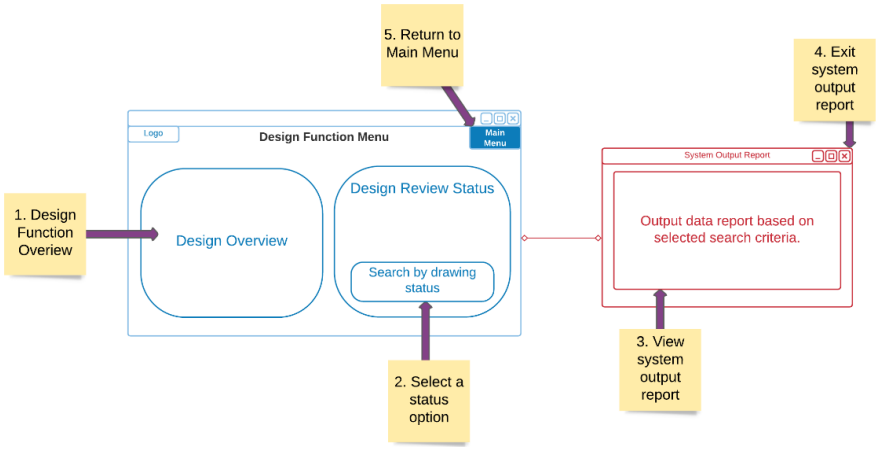
The materials function menu options are shown in Figure [Appendix Figure 3].



Appendix Figure 3: Materials Function UI

Design Function UI

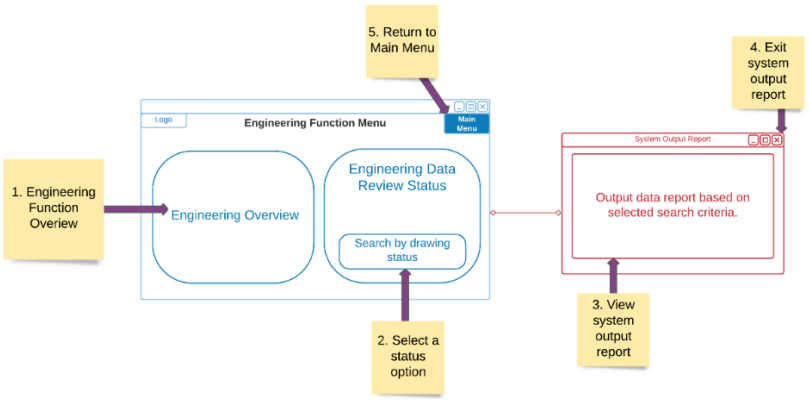
The design function menu options are shown in Figure [Appendix Figure 4].



Appendix Figure 4: Design Function UI

Engineering Function UI

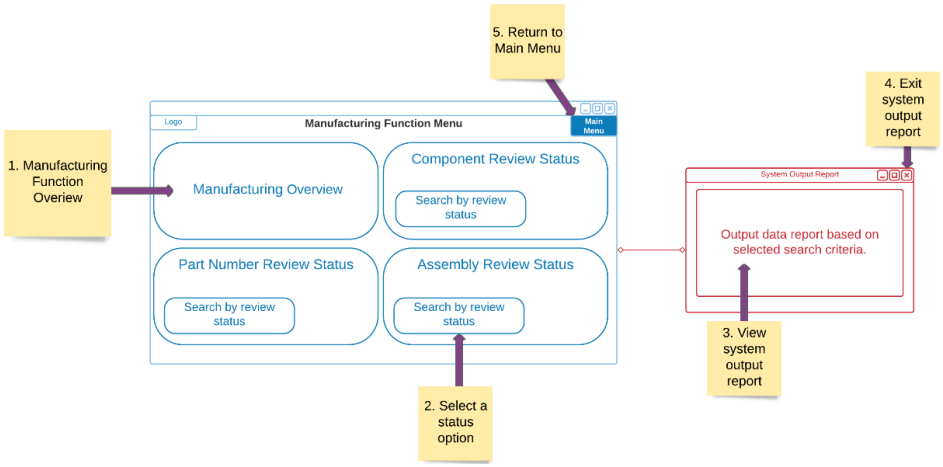
The engineering function menu options are shown in Figure [Appendix Figure 5].



Appendix Figure 5: Engineering Function UI

Manufacturing Function UI

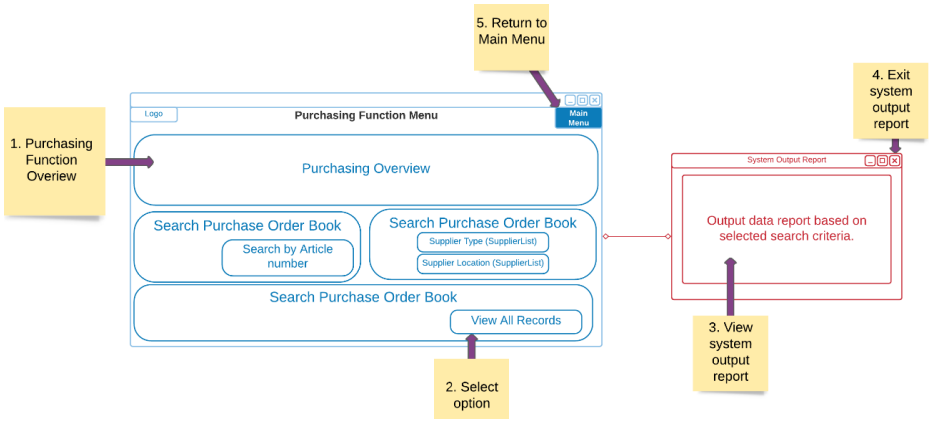
The manufacturing function menu options are shown in Figure [Appendix Figure 6].



Appendix Figure 6: Manufacturing Function UI

Purchasing Function UI

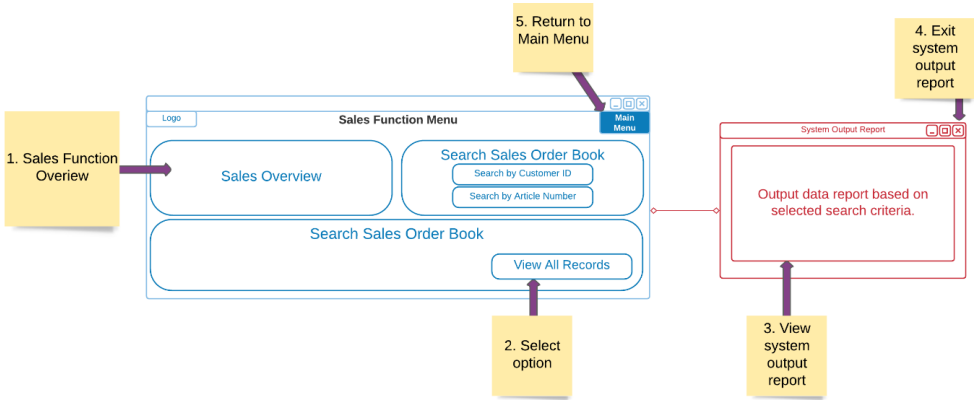
The purchasing function menu options are shown in Figure [Appendix Figure 7].



Appendix Figure 7: Purchasing Function UI

Sales Function UI

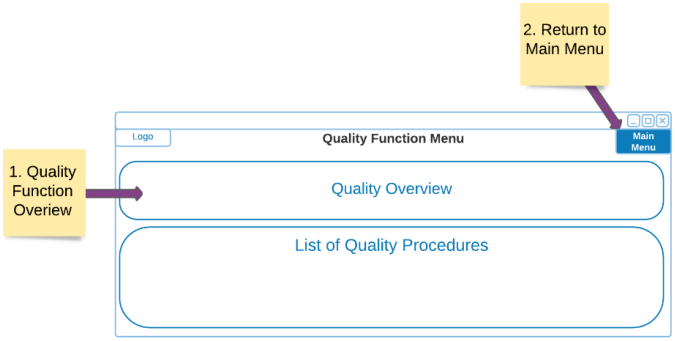
The sales function menu options are shown in Figure [Appendix Figure 8].



Appendix Figure 8: Sales Function UI

Quality Function UI

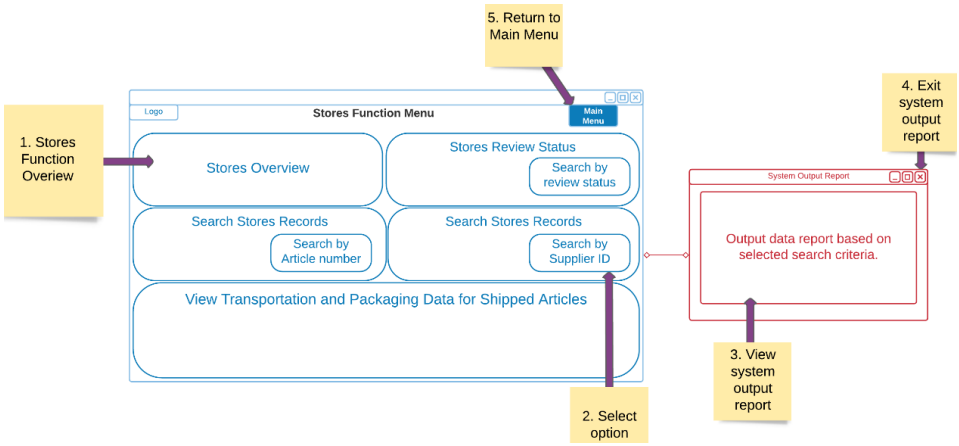
The quality function menu options are shown in Figure [Appendix Figure 9].



Appendix Figure 9: Quality Function UI

Stores Function UI

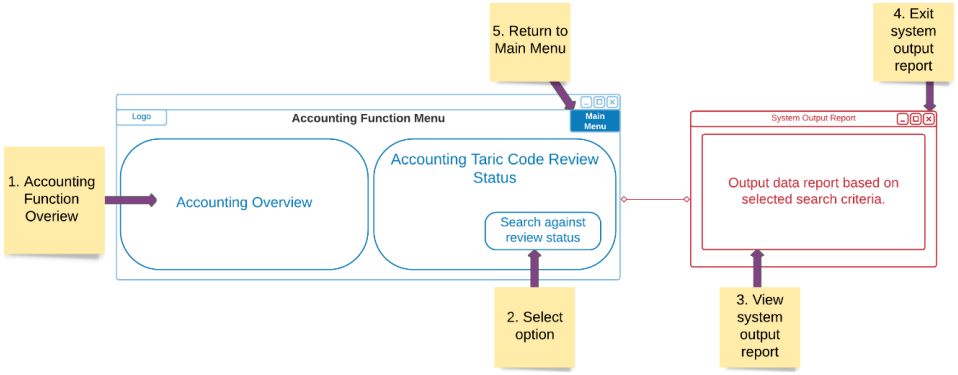
The store's function menu options are shown in Figure [Appendix Figure 10].



Appendix Figure 10: Stores Function UI

Accounting Function UI

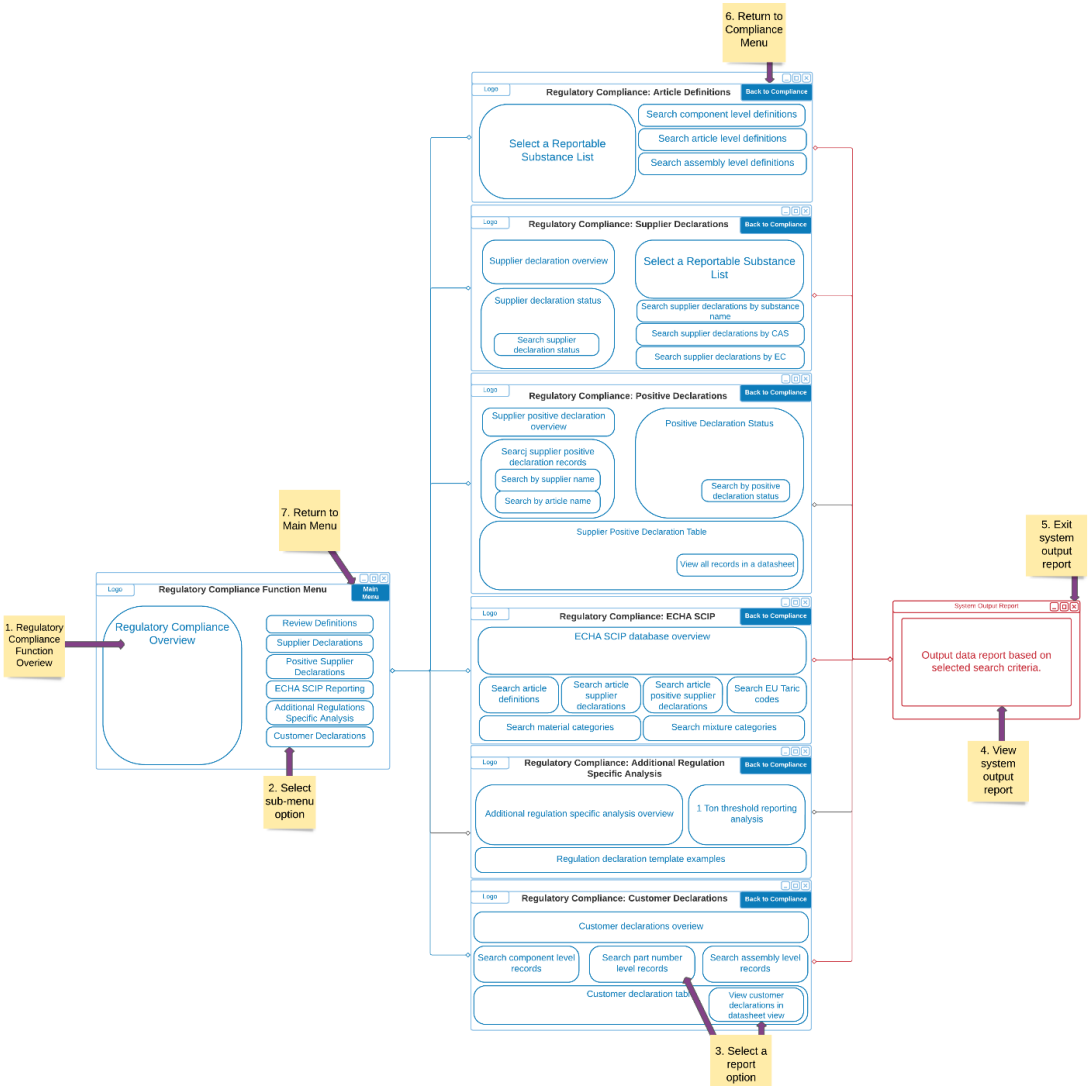
The accounting function menu options are shown in Figure [Appendix Figure 11].



Appendix Figure 11: Accounting Function UI

Regulatory Compliance Function UI

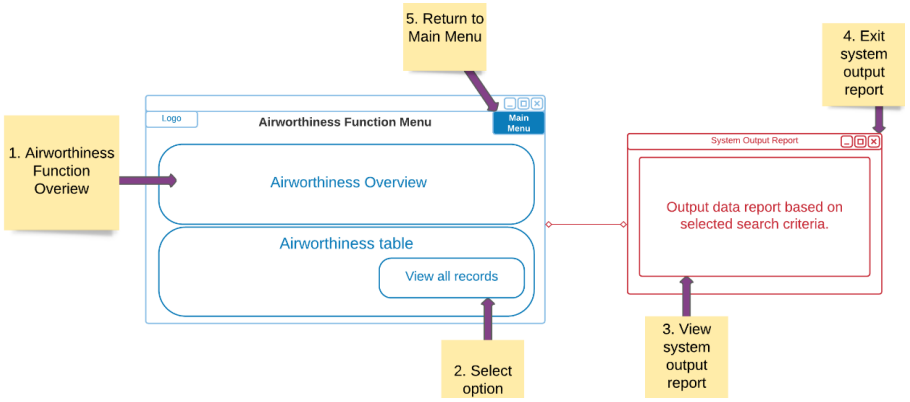
The regulatory compliance function menu options are shown in Figure [Appendix Figure 12].



Appendix Figure 12: Regulatory Compliance Function UI

Airworthiness Function UI

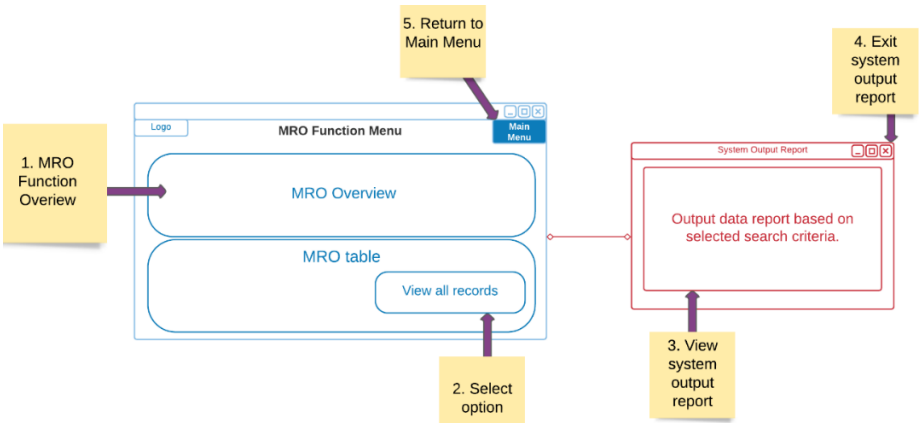
The regulatory compliance function menu options are shown in Figure [Appendix Figure 13].



Appendix Figure 13: Airworthiness Function UI

MRO Function UI

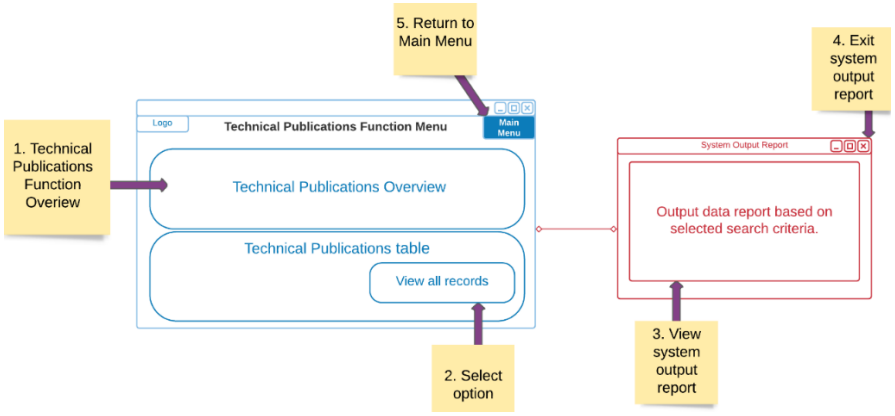
The MRO function menu options are shown in Figure [Appendix Figure 14].



Appendix Figure 14: MRO Function UI

Technical Publications Function UI

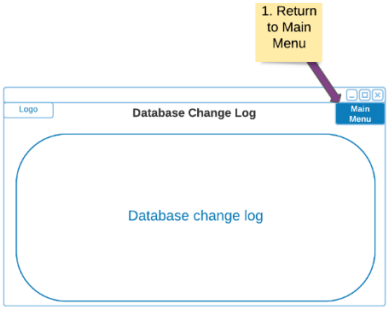
The technical publication's function menu options are shown in Figure [Appendix Figure 15].



Appendix Figure 15: Technical Publications UI

Change log

The database change log is shown in Figure [Appendix Figure 16].



Appendix Figure 16: Database Change Log UI

As any changes are made to the application, the database change log should be updated to reflect the nature of the changes made.

Appendix 8: Database Application Configuration Instructions

This section describes the configuration instructions for the database application:

Database Application Prerequisite's

The following prerequisites represent the minimal set of items needed to run the application:

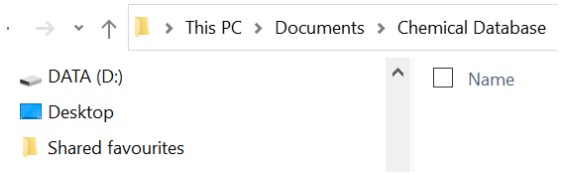
- Physical / Virtual computer running MS Windows 10 operating system software.
- At least 4GB of RAM (ideally 8GB RAM or higher for improved processing).
- Local device storage of at least 26MB.
- MS-Office application suite, version 2016 or higher, which has MS-Excel and MS-Access installed locally on the physical / virtual computer.
- Video display set to up to 2560 x 1440, which allows the images within the menu in the application to be displayed correctly.

- The application can function on a higher resolution setting, but the function menu figures may not display as intended.

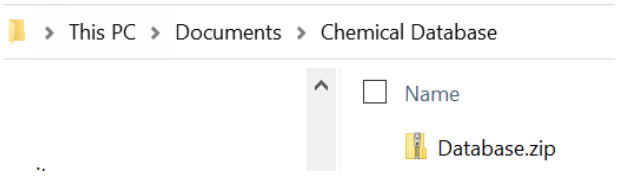
Download Application and Extract Files

The following steps outline the installation and configuration of the data template files within the application:

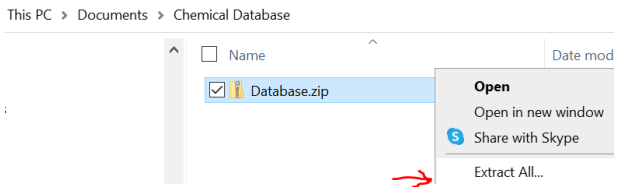
- Open windows explorer.
- Navigate to my documents and create a new folder to store the database, in the example below this folder has been named **Chemical Database [any logical name will suffice].**



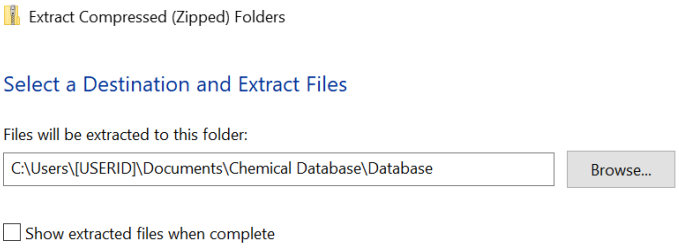
- Download the application and template files from this location by clicking on this link.
- The database.zip package will then be downloaded onto to the local computer.
- Use windows explorer and copy the database.zip file from downloads to Documents / Chemical Database folder created earlier.



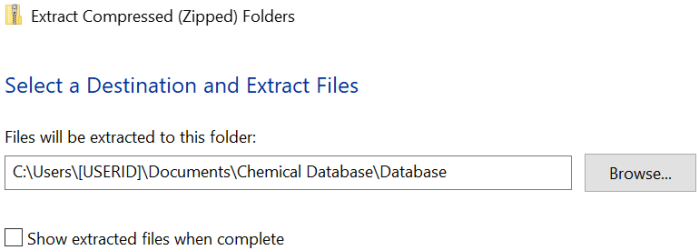
- Highlight the database.zip file, right-click and select extract all to the location.



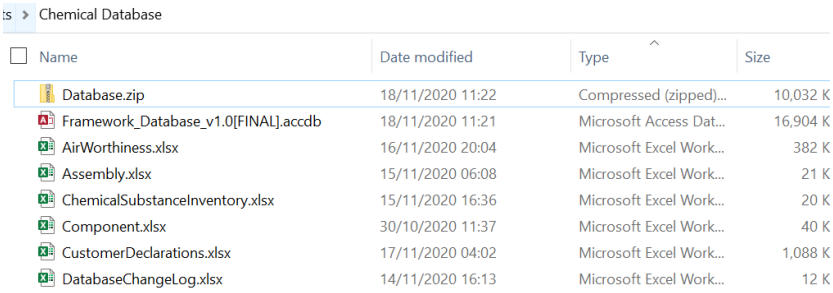
- A pop-up window will appear.



- Adjust the extract folder to become C:\Users\[USERID]\Documents\Chemical Database.



- Click on **Extract**



- The required files should now be extracted and ready to be imported and configured within the application.

Data Load Template Files That Need to be Imported and Configured

Table [Appendix Table 1] defines the data template files that need to be imported into the application.

Appendix Table 1: List of Data Load Templates to be Configured Within Database Application

Template file name	Linked table name	Imported
AirWorthiness.xlsx	AirWorthiness	YES / NO
Assembly.xlsx	Assembly	YES / NO
ChemicalSubstanceInventory.xlsx	MasterChemicalInventoryList	YES / NO
Component.xlsx	Component	YES / NO
CustomerDeclarations.xlsx	CustomerDeclarations	YES / NO
DatabaseChangeLog.xlsx	ChangeLog	YES / NO
DetailedDeclaration.xlsx	DetailedDeclaration	YES / NO
DetailedDSL.xlsx	DetailedDSL	YES / NO
Drawing.xlsx	Drawings	YES / NO
DSLReference.xlsx	DSLReference	YES / NO
Engineering.xlsx	Engineering	YES / NO
Material.xlsx	Material	YES / NO
Mixture.xlsx	Mixture	YES / NO
MRO.xlsx	MRO	YES / NO
Packaging.xlsx	Packaging	YES / NO
PartNumber.xlsx	PartNumber	YES / NO
PositiveDeclaration.xlsx	PositiveDeclaration	YES / NO
PurchasingForwardLoad.xlsx	PurchasingForwardLoad	YES / NO
Quality.xlsx	Quality	YES / NO
RegCompAssessment.xlsx	RegCompAssessment	YES / NO
RequestorGDPR.xlsx	RequestorGDPR	YES / NO
SafeUseGuidance.xlsx	SafeUseGuidance	YES / NO
SalesForwardLoad.xlsx	SalesForwardLoad	YES / NO
SalesGDPR.xlsx	SalesGDPR	YES / NO
SCIPEUTaricCodes.xlsx	EUTaricCode	YES / NO
SCIPMaterialCategories.xlsx	MaterialCategory	YES / NO
SCIPMixtureCategories.xlsx	MixtureCategories	YES / NO
Stores.xlsx	Stores	YES / NO
SubstanceAnalysis.xlsx	SubstanceAnalysis	YES / NO
SupplierDeclaration.xlsx	SupplierDeclaration	YES / NO
SupplierGDPR.xlsx	SupplierGDPR	YES / NO
SupplierList.xlsx	SupplierList	YES / NO
TechnicalPublications.xlsx	TechnicalPublications	YES / NO
Transport.xlsx	Transport	YES / NO

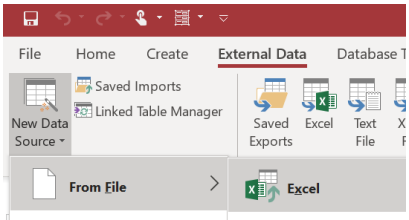
Launch Database Application and Configure Data Load Template Files

The following steps outline launching the application from the location where the database.zip files were downloaded in the previous section.

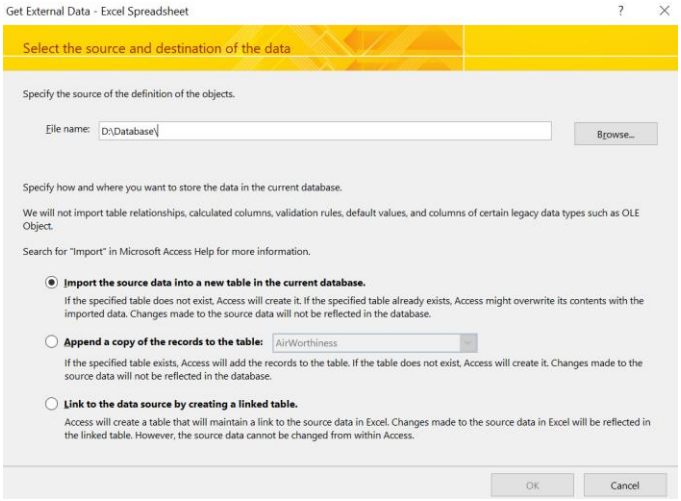
- From the extracted file location.
- Double click on the Framework_Database_v1.x[FINAL] file.

- The application should open in MS-Access as shown below:

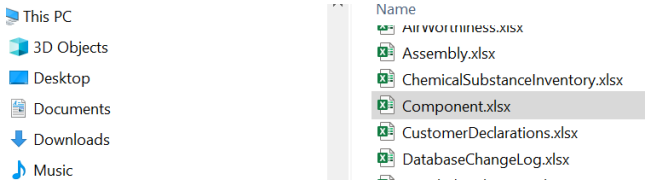
- Select -> External Data -> New Data Source -> From File -> Excel



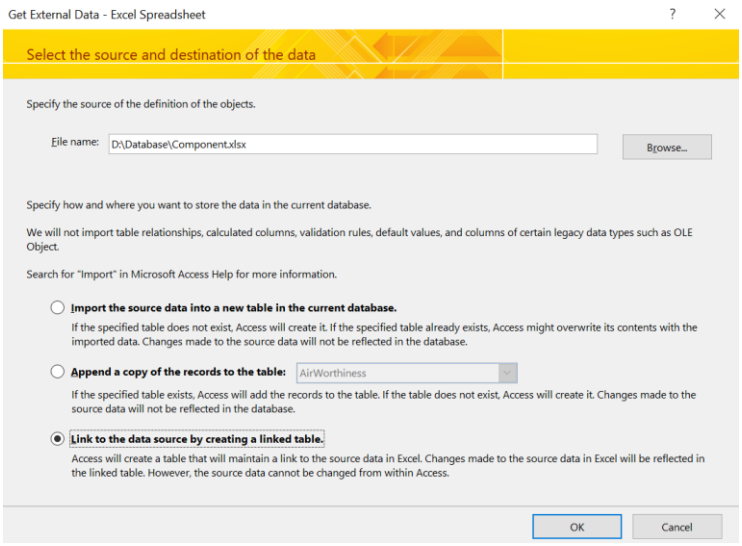
- A Get External Data – Excel Spreadsheet window will appear.



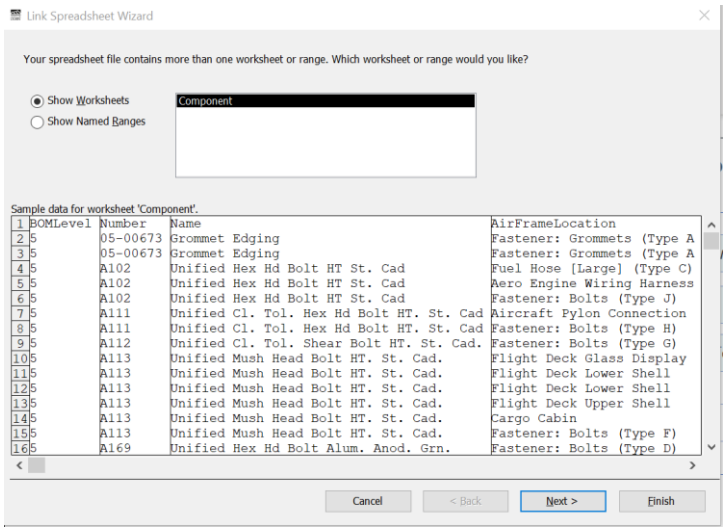
- Click on **Browse.**
- Navigate to the location of the locally stored template file.
- Select the applicable template file from Table [Appendix Table 1].



- Click on **Open.**
- Select Link to the data source by creating a linked table.

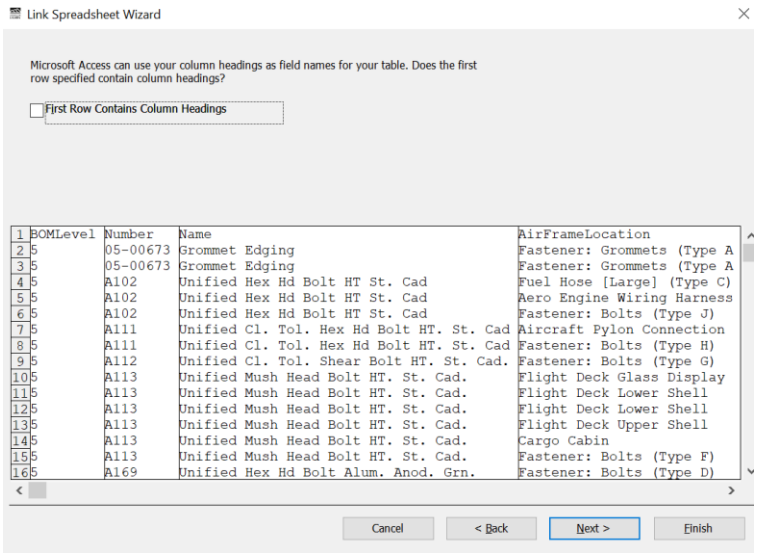


- Click on **OK.**



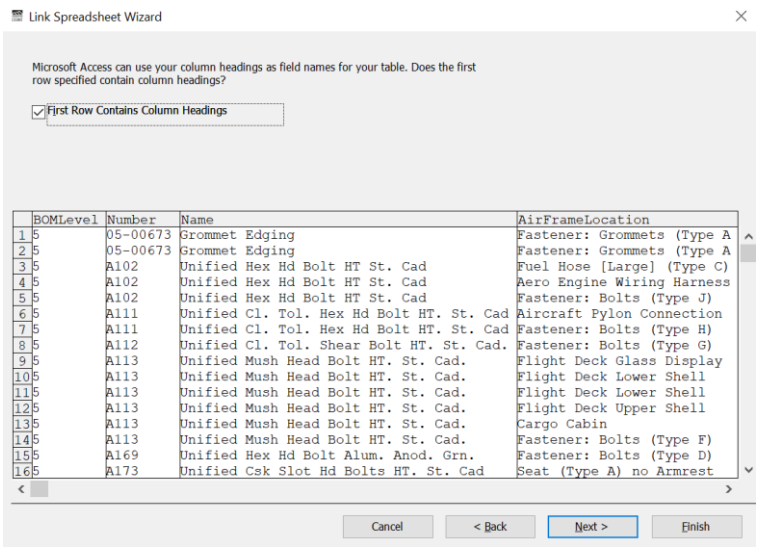
	BOMLevel	Number	Name	AirFrameLocation
2	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
3	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
4	5	A102	Unified Hex Hd Bolt HT St. Cad	Fuel Hose [Large] (Type C)
5	5	A102	Unified Hex Hd Bolt HT St. Cad	Aero Engine Wiring Harness
6	5	A102	Unified Hex Hd Bolt HT St. Cad	Fastener: Bolts (Type J)
7	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Aircraft Pylon Connection
8	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Fastener: Bolts (Type H)
9	5	A112	Unified Cl. Tol. Shear Bolt HT. St. Cad.	Fastener: Bolts (Type G)
10	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Glass Display
11	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
12	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
13	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Upper Shell
14	5	A113	Unified Mush Head Bolt HT. St. Cad.	Cargo Cabin
15	5	A113	Unified Mush Head Bolt HT. St. Cad.	Fastener: Bolts (Type F)
16	5	A169	Unified Hex Hd Bolt Alum. Anod. Grn.	Fastener: Bolts (Type D)

- Click on **Next**.



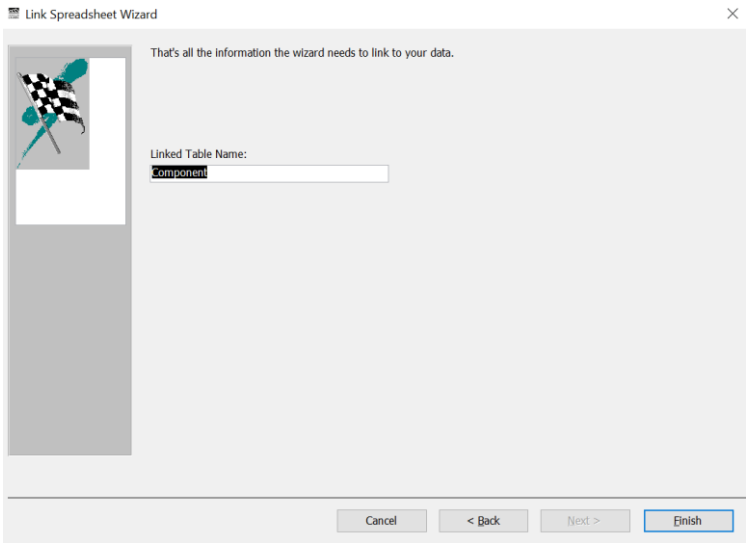
	BOMLevel	Number	Name	AirFrameLocation
2	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
3	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
4	5	A102	Unified Hex Hd Bolt HT St. Cad	Fuel Hose [Large] (Type C)
5	5	A102	Unified Hex Hd Bolt HT St. Cad	Aero Engine Wiring Harness
6	5	A102	Unified Hex Hd Bolt HT St. Cad	Fastener: Bolts (Type J)
7	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Aircraft Pylon Connection
8	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Fastener: Bolts (Type H)
9	5	A112	Unified Cl. Tol. Shear Bolt HT. St. Cad.	Fastener: Bolts (Type G)
10	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Glass Display
11	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
12	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
13	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Upper Shell
14	5	A113	Unified Mush Head Bolt HT. St. Cad.	Cargo Cabin
15	5	A113	Unified Mush Head Bolt HT. St. Cad.	Fastener: Bolts (Type F)
16	5	A169	Unified Hex Hd Bolt Alum. Anod. Grn.	Fastener: Bolts (Type D)

- Select First Row Contains Column Headings.

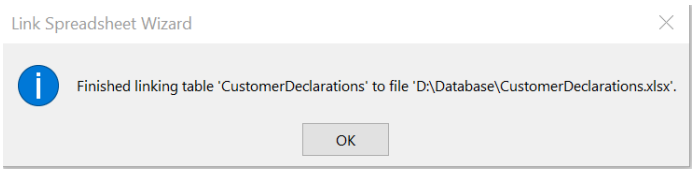


	BOMLevel	Number	Name	AirFrameLocation
1	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
2	5	05-00673	Grommet Edging	Fastener: Grommets (Type A
3	5	A102	Unified Hex Hd Bolt HT St. Cad	Fuel Hose [Large] (Type C)
4	5	A102	Unified Hex Hd Bolt HT St. Cad	Aero Engine Wiring Harness
5	5	A102	Unified Hex Hd Bolt HT St. Cad	Fastener: Bolts (Type J)
6	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Aircraft Pylon Connection
7	5	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	Fastener: Bolts (Type H)
8	5	A112	Unified Cl. Tol. Shear Bolt HT. St. Cad.	Fastener: Bolts (Type G)
9	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Glass Display
10	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
11	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Lower Shell
12	5	A113	Unified Mush Head Bolt HT. St. Cad.	Flight Deck Upper Shell
13	5	A113	Unified Mush Head Bolt HT. St. Cad.	Cargo Cabin
14	5	A113	Unified Mush Head Bolt HT. St. Cad.	Fastener: Bolts (Type F)
15	5	A169	Unified Hex Hd Bolt Alum. Anod. Grn.	Fastener: Bolts (Type D)
16	5	A173	Unified Csk Slot Hd Bolts HT. St. Cad	Seat (Type A) no Armrest

- Click on **Next.**
- Do not change the Linked Table Name.



- Click on **Finish.**
- A pop-up window will appear confirming that the database has linked to a locally stored file.



- Click on **OK.**
- Repeat the process for all template files downloaded as per Table [10-6].
- The application should now be installed, and the data template files configured for use.

- The system output reports, may now be run showing data based on the contents of a given data template file that has been imported into the application.

Appendix 9: Dashboard Application Configuration Instructions

This section describes the configuration instructions for the Dashboard application:

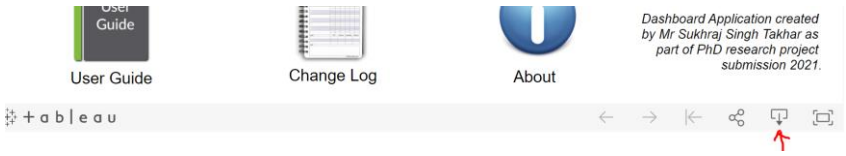
Dashboard Application Prerequisite's

The following prerequisites represent the minimal set of items needed to run the application:

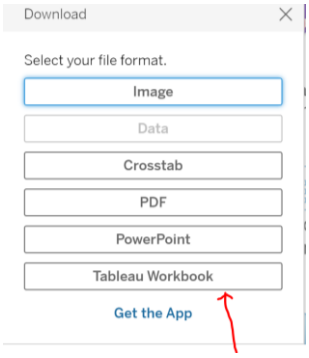
- Online:
  - A computer running an operating system.
  - At least 4GB of RAM.
  - A web browser application capable of connecting to the published dashboard application.
- Local:
  - A computer running an operating system.
  - At least 4GB of RAM (ideally 8GB RAM or higher for improved processing).
  - Local device storage:
    - 5GB disk space for the Tableau Desktop application.
    - 20MB to download the Dashboard application + associated data load templates.
  - A local copy of Tableau Desktop application from version 2020.4 or higher. The local copy of Tableau Desktop is only required when making changes to the source data load template files.
  - MS-Office application suite, version 2016 or higher, which has MS-Excel installed locally on the physical / virtual computer.

Download Dashboard Application and Extract Files (Local Dashboard Application Only)

- A computer running an operating system.
- Open the following URL to view the application online, using a web browser.
- The latest version of the Dashboard may be downloaded by selecting the download icon.



- A pop-up window will appear.
- Select the download the **Tableau Workbook** option.

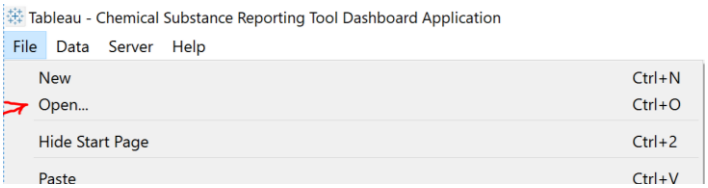


- The application should now be downloaded to the local downloads folder on the PC / MAC.
- The Dashboard application may now be launched locally using the tableau desktop application.
- Open windows explorer.
- Navigate to my documents and create a new folder to store the dashboard application.
- Create a new folder called **Dashboard**.
- Copy the downloaded Dashboard application to this location.
- Click on OneDrive shared location, the latest version of the dashboard data load templates will be downloaded.
- Close any open web browsers.
- Within windows explorer, create a new folder under Dashboard, name as **DataLoadTemplates**.
- Copy the downloaded data load templates into this location.
- Extract the .zip file once copied.
- The data load templates should now be available under **Documents/Dashboard/DataLoadTemplates**, there should be 38 files and folders:

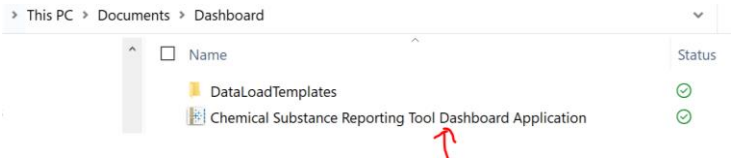
Reference Tables	26/03/2021 13:46	File folder	
AirWorthiness	24/03/2021 04:33	Microsoft Excel W...	383 KB
Assembly	31/03/2021 18:44	Microsoft Excel W...	22 KB
ChemicalSubstanceInventory	15/11/2020 15:36	Microsoft Excel W...	20 KB
Component	24/03/2021 04:47	Microsoft Excel W...	40 KB
CustomerDeclarations	27/11/2020 16:33	Microsoft Excel W...	1,088 KB
DashboardChangeLog	06/04/2021 06:46	Microsoft Excel W...	11 KB
Data_Load_Templates	06/04/2021 13:24	WinRAR ZIP archive	18,312 KB
DetailedDeclaration	17/02/2021 05:59	Microsoft Excel W...	6,605 KB
DetailedDSL	21/03/2021 18:24	Microsoft Excel W...	9,683 KB
Drawing	18/02/2021 18:41	Microsoft Excel W...	52 KB
DSLReference	22/03/2021 05:56	Microsoft Excel W...	16 KB
ECHASubInfoCardData	01/03/2021 04:29	Microsoft Excel W...	385 KB
Engineering	24/12/2020 09:43	Microsoft Excel W...	13 KB
Material	03/01/2021 02:52	Microsoft Excel W...	12 KB
Mixture	03/01/2021 02:49	Microsoft Excel W...	27 KB
MRO	27/11/2020 16:33	Microsoft Excel W...	16 KB
Packaging	26/02/2021 14:46	Microsoft Excel W...	11 KB
PartNumber	04/02/2021 07:09	Microsoft Excel W...	92 KB

Launch Dashboard Application and Configure Data Load Templates *(Local Dashboard Application Only)*

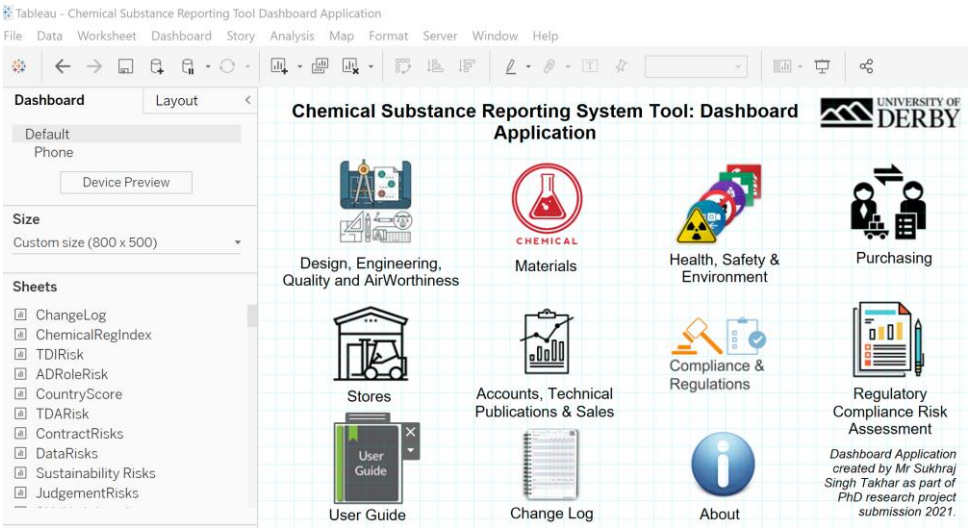
- Launch Tableau Desktop on local PC.
- Tableau will open.
- Select File → Open



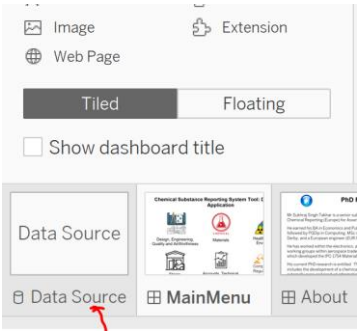
- Navigate to Documents/Dashboard and select Chemical Substance Reporting Tool Dashboard Application.



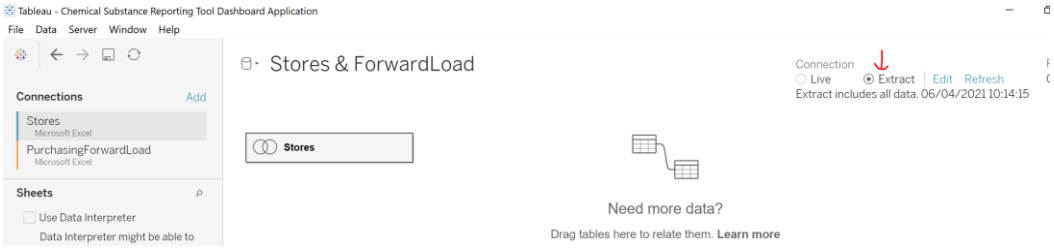
- The dashboard application will now open in Tableau Desktop:



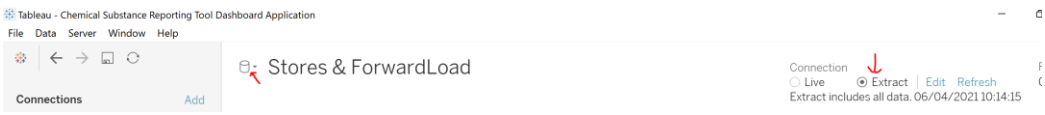
- The data load templates now need to be configured to work with the local copy of the Dashboard application.
- **Click on the Data Source** button in the bottom left-hand corner:



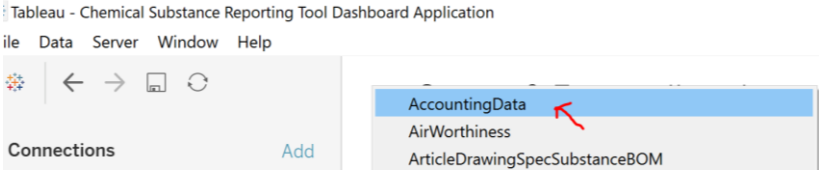
- As the Dashboard Application was published onto the Tableau public server, the data load files had to imported into the Tableau Desktop application as local extracts.
- The next few steps need to be repeated for all data sources to ensure the Tableau Desktop application is configured to work with the downloaded data load template files.
- With the first data source, we can see the connection is set to **extract**:



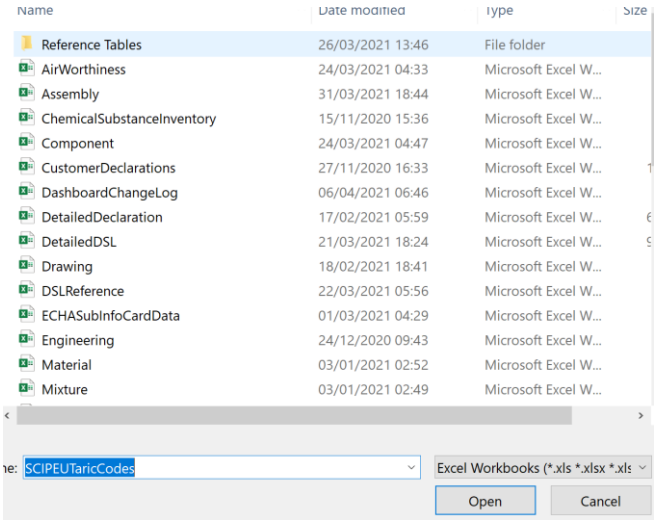
- Click into the database icon:



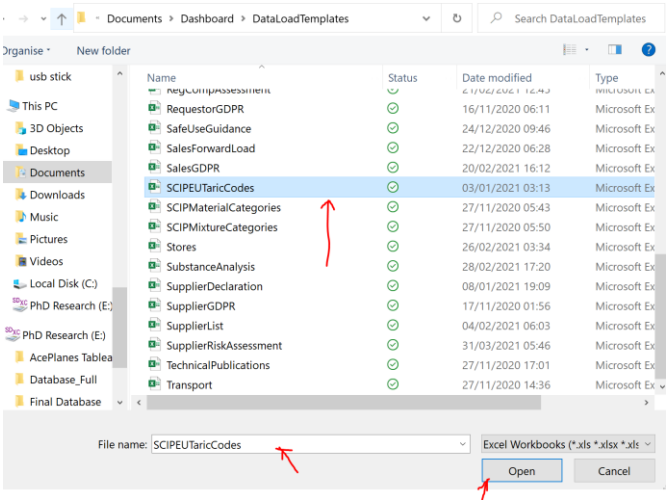
- Select a database table



- Tableau desktop application will attempt to load the data load template and fail as it has not been defined locally, instead a pop-up window will appear asking to confirm location.



- Navigate to Documents/**Dashboard/DataLoadTemplates**, and select the data load template where the name matches the value Tableau Desktop believes is defined:



- Ensure file name Tableau Desktop has identified matches the name of the applicable data load template defined under/**Dashboard/DataLoadTemplates**.

- Tableau Desktop will now reference the applicable data load template as opposed to its internal extracts.

Repeat the process with all applicable database tables, importing them one by one. Table [Appendix Table 2] defines the data template files that need to be imported into the application.

Appendix Table 2: List of Tables That Need To Be Configured Within Dashboard Application

Database Table Name	Data Load File Name	Required
AccountingData	SCIPEUTaricCodes.xlsx	YES
AirWorthiness	AirWorthiness.xlsx	YES
ArticleDrawingSpecSubstanceBOM	Assembly.xlsx PartNumber.xlsx Component.xlsx	YES
ArticleSpecSubstanceBOM	Assembly.xlsx PartNumber.xlsx Component.xlsx	YES
Assembly	Assembly.xlsx	YES
Assembly (BOM)	Assembly.xlsx Drawings.xlsx SubstanceAnalysis.xlsx DetailedDSL.xlsx	YES
ChangeLog (DashboardChangeLog)	DashboardChangeLog.xlsx	YES
Component	Component.xlsx	YES
ComponentBOM	Component.xlsx Drawings.xlsx SubstanceAnalysis.xlsx DetailedDSL.xlsx	YES
CustomerDeclarations	CustomerDeclarations.xlsx	YES
DetailedDSL	DetailedDSL.xlsx	YES
DrawingData	Drawing.xlsx	YES
DSLReference	DSLReference.xlsx	YES
ECHASubInfoCardData	ECHASubInfoCardData.xlsx	YES
Engineering	Engineering.xlsx	YES
MasterBOM	Assembly.xlsx Component.xlsx Drawings.xlsx SubstanceAnalysis.xlsx DetailedDSL.xlsx	YES
MasterChemicalInventoryList	ChemicalSubstanceInventory.xlsx	YES
MaterialsMaterial	Material.xlsx	YES
MaterialsMixture	Mixture.xlsx	YES
Packaging (Multiple Connections)	Packaging.xlsx	YES
PartNumber	PartNumber.xlsx	YES
PartNumberBOM	PartNumber.xlsx	YES
PositiveDeclarationData	PositiveDeclaration.xlsx	YES
PurchasingForwardLoad	PurchasingForwardLoad.xlsx	YES
Quality	Quality.xlsx	YES
RegCompAssessment (RegCompAssessment)	RegCompAssessment	YES
SalesForwardLoad (SalesForwardLoad)	SalesForwardLoad.xlsx	YES
SalesGDPR	SalesGDPR.xlsx	YES
Stores	Stores.xlsx	YES

Database Table Name	Data Load File Name	Required
Stores & ForwardLoad	Stores.xlsx	YES
SubstanceAnalysis	SubstanceAnalysis.xlsx	YES
SubstanceComplianceStatus	RegCompAssessment.xlsx	YES
SupplierDeclarationData	Assembly.xlsx Component.xlsx DetailedDSL.xlsx PartNumber.xlsx SalesGDPR.xlsx	YES
SupplierList+ (Multiple Connections)	SupplierList.xlsx SupplierGDPR.xlsx DetailedDeclaration.xlsx	YES
SupplierRiskAssessment (SupplierRiskAssessment)	SupplierRiskAssessment.xlsx	YES
TechnicalPublications	TechnicalPublications.xlsx	YES

The required files should now be extracted and ready to be imported and configured within the application.

Appendix 10: Technical Design Authority (TDA) Analysis Criteria

The Technical Design Authorities (TDA) are defined based on the literature review findings. Table [Appendix Table 3] defines the assumed TDA types in scope. This is an informative analysis which can be used in conjunction with TDI and SIA tables. To accurately identify this type of data the BOMType field was utilised to reflect if an article is defined internally or externally.

Appendix Table 3: TDA Analysis

Role	Description	Context within research
ODM Defined	• Generate article designs, where the manufacturing of articles may be licensed to different organisations. • Designs cover geometry and specifications (where applicable). • Specifications typically define Mandatory and optional substances.	• Review internal article definitions.
OEM Defined	• Design and manufacture articles internally or using other supply chain actors • Designs cover geometry and specifications (where applicable). • Specifications typically define Mandatory and optional substances.	
Customer Requirements	• ODM / OEM generates design documentation based on specific customer requirements.	
Build to Print Suppliers	• Produce articles to precise OEM / ODM design and material specifications	• Collect data from the supply chain.
Build to Specification Suppliers	• Like build to print suppliers, however suppliers are allowed flexibility in the selection of materials which can be used.	
Joint Ventures / Risk & Revenue Sharing Suppliers	• Costs of Article design and development are shared between a buying organisation and its supplier are shared as is the future potential revenue from a given article.	

Role	Description	Context within research
Industry Standard Parts	• Common industry specifications that define the materials and / or geometry of articles. • Articles are then manufactured by suppliers.	
Wholly Supplier Defined.	• Supplier responsible for design and materials.	

Appendix 11: AD Organisation Role (ADOR) Analysis Criteria

This table is generated to identify the role of the AD organisation in the context of how an article is designed, manufactured, or consumed. This data informs data requirement needs. Table [Appendix Table 4] defines the applicable roles.

Appendix Table 4: ADOR Analysis

Role	Article Manufacturer	Article Importer	Article Supplier	Article Distributor	Article Recipient
Description	• Manufacturer of the original article (chemical substance, mixture, material, component, part number or assembly). • Should be aware of the chemicals used.	• Can be the original article manufacturer. • If not the original article manufacturer, then the importer will need to collate data from the original article manufacturer.	• Can be the original article manufacturer / importer. • If not the original article manufacturer, then the supplier will need to collate data from the original article manufacturer.	• Can be the original article manufacturer / importer. • If not the original article manufacturer, then the distributor will need to collate data from the original article manufacturer.	• AD organisation customer that receipts the article. • Requires relevant regulatory compliance statements (Customer Declarations).

Appendix 12: Chemical Regulation Index (CRI) Analysis Criteria

The CRI table assigns a criticality level to a reportable substance list defined within a chemical regulation, using a scale of 1-5. Table [Appendix Table 5] defines the index scores defined against the DSLs recorded in a new data field within the DSLReference data load template. The role of the CRI table is to help model potential risks for a given article, whether internally manufactured or sourced from the supply chain. Where the higher the score for an article containing any reportable chemicals of concern, results in a greater potential risk. The author has chosen this approach to avoid any bias in terms of assumed chemicals of concern within the AD sector.

Appendix Table 5: CRI Analysis

Indicator	Score / index value	Applicable Chemical Regulation Declarable Substance Lists
Low (L)	1	• ChemSec Substitute It Now! (SIN) List. • Critical Raw Materials for Electronics sector. • EU Biocidal Products Regulation List of Active Substances (EU BPR). • Cancelled Active Substances.

Indicator	Score / index value	Applicable Chemical Regulation Declarable Substance Lists
		• EU Regulatory Management Option Analysis (RMOA) substances awaiting further action. • US California Prop 65. • US TSCA List of Chemicals Undergoing Risk Evaluation. • US TSCA Low-Priority Substances List. • US NAS 411-1 (2015).
Low-Medium (LM)	2	• Canada Toxic Substances List • Critical Raw Materials for Transportation sector. • EU Critical Raw Materials List (EU CRM). • EU REACH Candidate List of Substances Non-Exhaustive Expanded Substances. • EU Restriction of Hazardous Substances List (RoHS) for Electronics Non-Exhaustive Expanded Substances. • South Korea K-REACH Restricted Substances List. • Turkey Annex 17 Restricted Substances List.
Medium (M)	3	• Critical Raw Materials for AD sector. • EU Batteries Directive. • EU Biocidal Products Regulation List of Active Substances (EU BPR) Pending Active Substances. • EU Conflict Minerals Substances List (EU CMR). • EU Nanomaterial Substances List. • EU REACH Candidate List of Substances. • IAEG AD Declarable Substance List (AD-DSL). • US Conflict Mineral Substances List (US CMR). • US NAS 411-1 (2020) – Tracked. • EU Fluorinated Gas Regulation. • UK REACH Candidate List of Substances.
Medium-High (M-H)	4	• Collins Aerospace: Materials of Concern List. • EU Biocidal Products Regulation List of Active Substances (EU BPR) Approved Active Substances. • EU REACH Authorisation List of Substances (Annex XIV). • EU Restriction of Hazardous Substances List (RoHS) for Electronics. • US NAS 411-1 (2020) – Restricted. • US TSCA Persistent Bioaccumulative and Toxic Chemicals under TSCA Section 6(h). • UK REACH Authorisation List of Substances.
High (H)	5	• EU Persistent Organic Pollutants List (EU POPS). • EU Radioactive Substances List. • EU REACH Restricted List of Substances (Annex XVII). • US NAS 411-1 (2020) – Prohibited.

Appendix 13: Technical Documentation Index (TDI) Analysis Criteria

TDI defines a ranking score based on identified technical documentation, collated from either AD organisation internal documents or extracted from supply chain material declarations. Table [Appendix Table 6] defines the assessment criteria for the TDI table.

Appendix Table 6: TDI Analysis

Indicator	Score / index value	Assessment of existing documentation (internal and external)
No DATA	0	• Where a supplier is defined with no related article being shown either on the **PurchaseForwardLoad** data temple or **DetailedDeclaration** data load template, then a default value of 0 was assigned as this as deemed a combination of no articles on order resulting in a lack of data to support chemical risk assessment.

Indicator	Score / index value	Assessment of existing documentation (internal and external)

Low (L)	1	• Regular cadence to request supply chain data as regulatory reportable substance lists are updated.
		• (a) Supply chain data collection processes established.
		  ○ Contractual terms, frequency and formats agreed:
		  ▪ Full Material Declarations (optional)
		  ▪ Material declarations in standard data exchange formats: IPC-1752A, IPC-1752, IPC-1754 and IEC 62474.
		  ▪ Positive declaration statements collected from suppliers reporting hazardous chemicals (optional)
		• (b) Internal definitions:
		  ○ Mapped from drawings / specification through to substances consumed in the final articles placed onto the marketplace.
		• Date from (a) and (b) contrasted with chemical regulation declarable substance lists, to identify resultant risks and obligations.
		• In the event of no other data being readily available:
		  ○ NDT / XRF testing of an article to identify chemicals present on the finished article, in lieu of any other data – Assumption is that the data is less than 12 months old.

Low-Medium (L-M)	2	• Ad-hoc cadence to request supply chain data (>12 but <18 months).
		• (a) Supply chain data collection process being established.
		  ○ Not all suppliers responding to data requests.
		  ○ Contractual obligations to be defined in supplier contracts, covering frequency and data formats.
		• (b) Internal definitions:
		  ○ Mapped from drawings / specification through to substances consumed in the final articles placed onto the marketplace.
		• Date from (a) and (b) contrasted with chemical regulation declarable substance lists, to identify resultant risks and obligations.
		• In the event of no other data being readily available:
		  ○ NDT / XRF testing of an article to identify chemicals present on the finished article, in lieu of any other data – Assumption is that the data is >12 months but <18 months old.
		• Where lack of any detailed definition data (internal / external) being available:
		  ○ Data collection based on either industry standard specifications or;
		  ○ Data collection based on information relating to chemical substances, mixtures, and materials: (i) Material Safety Data Sheets (MSDS); (ii) Safety Data Sheets (SDS), and (iii) electronic Safety Data Sheets (eSDS)
		  ○ At this level the data is based on calculation of chemical substance presence based on the values presented in industry standards / data sheets.
		  ○ Assumption data is >12 months but <18 months old.

Medium (M)	3	• Ad-hoc cadence to request supply chain data (>18 but <24 months).
		• (a) Limited supply chain data collection process being established.
		• (b) Internal definitions:
		  ○ Mapped from drawings / specification through to substances consumed in the final articles placed onto the marketplace.
		• Date from (a) and (b) contrasted with chemical regulation declarable substance lists, to identify resultant risks and obligations.
		• In the event of no other data being readily available:
		  ○ NDT / XRF testing of an article to identify chemicals present on the finished article, in lieu of any other data – Assumption is that the data is >18 months but <24 months old.
		• Where lack of any detailed definition data (internal / external) being available:
		  ○ Data collection based on either industry standard specifications or;
		  ○ Data collection based on information relating to chemical substances, mixtures, and materials: (i) Material Safety Data Sheets (MSDS); (ii) Safety Data Sheets (SDS), and (iii) electronic Safety Data Sheets (eSDS)
		  ○ At this level the data is based on calculation of chemical substance presence based on the values presented in industry standards / data sheets.
		  ○ Assumption data is data is >18 months but <24 months old.
		• No detailed definition data (internal / external) readily available:
		  ○ Data collection based on either industry standard specifications or;

Indicator	Score / index value	Assessment of existing documentation (internal and external)
		○ Data collection based on information relating to chemical substances, mixtures, and materials: (i) Material Safety Data Sheets (MSDS); (ii) Safety Data Sheets (SDS), and (iii) electronic Safety Data Sheets (eSDS) ○ At this level the data is based on calculation of chemical substance presence based on the values presented in industry standards / data sheets. ○ Assumption data is data is >18 months but <24 months old.
Medium-High (MH)	4	• Ad-hoc cadence to request supply chain data (>24 months). • (a) Limited supply chain data collection process being established. • (b) Internal definitions: ○ Mapped from drawings / specification through to substances consumed in the final articles placed onto the marketplace. • Date from (a) and (b) contrasted with chemical regulation declarable substance lists, to identify resultant risks and obligations. • In the event of no other data being readily available: ○ NDT / XRF testing of an article to identify chemicals present on the finished article, in lieu of any other data – Assumption is that the data is >24 months old. • Where lack of any detailed definition data (internal / external) being available: ○ Data collection based on either industry standard specifications or; ○ Data collection based on information relating to chemical substances, mixtures, and materials: (i) Material Safety Data Sheets (MSDS); (ii) Safety Data Sheets (SDS), and (iii) electronic Safety Data Sheets (eSDS) ○ At this level the data is based on calculation of chemical substance presence based on the values presented in industry standards / data sheets. ○ Assumption data is data is >24 months old. • No detailed definition data (internal / external) readily available: ○ Data collection based on either industry standard specifications or; ○ Data collection based on information relating to chemical substances, mixtures, and materials: (i) Material Safety Data Sheets (MSDS); (ii) Safety Data Sheets (SDS), and (iii) electronic Safety Data Sheets (eSDS) ○ At this level the data is based on calculation of chemical substance presence based on the values presented in industry standards / data sheets. ○ Assumption data is data is >24 months old.
High (H)	5	• Only basic data known for articles: ○ Industry standard article names (sourced from multiple suppliers). ○ Internal article numbers / names. ○ Supplier article numbers / names.

Appendix 14: Supplier Integrity Assessment (SIA) Analysis Criteria

Appendix Table 7: Supplier Integrity Assessment (SIA) Analysis Criteria

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
1.	Contractual terms *(Mandatory check).*	Review supplier Master Services Agreement (MSA) / Service Level Agreement (SLA) which is established as an output of buyer supplier contract negotiations.						Score based on identified data at the supplier level.
		• Are there any specific chemical regulations defined for suppliers to report against? – are there against specific publication date / versions of a regulation?			**X**	**X**	**X**	Where the risk scale is assumed to be: (1) 3: Supplier will only report against the current version(s) of agreed regulation(s); (2) 4 and 5: Supplier is reporting against outdated versions of a regulation or just the name of the regulation – data provided by the supplier does not clearly identify version or publication date of a regulatory substance list.
		• Is there a dynamic list of chemical regulations? (optional)	**X**					AD organisation defines a dynamic chemical regulation for its supply chain tiers to report against.
		• Can the supplier provide Full Material Declarations (FMD)? (optional)	**X**					Supplier is willing to provide a full list of chemical substances and mixtures contained within supplied articles, only providing delta updates when alternative substances and mixtures are used, as opposed to reporting against each chemical regulation update. In this use case having an FMD will result in a -1 score (negative) as it
		• Does the supplier have established processes to collect data from their respective supply chains?	**X**	**X**	**X**	**X**	**X**	Identify types of reporting and frequency of data collected from the supply chain. The more established a process is the lower the score.
2.	Supplier Country of location analysis *(Mandatory check).*	This analysis is conducted using several indexes identifying risks at a country level.						Risk scores at country level where supplier organisation is located.
		• Check country locations in terms of UN Human Rights special procedure visits.	**X**	**X**	**X**	**X**	**X**	Data has been extracted from UN Human Rights Council special procedure visits – as shown UNHR table, countries have been scored in terms of number of special procedure visits conducted historically This scale counts the sum of all special procedure visits regardless of whether they have been completed / denied. The UN HRC index covers both human rights and several other areas of investigation. . Risk Scale based on total special procedures (1: 0-9, 2: 10-19, 3: 20-29, 4: 30-39, 5: 40+)

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
		• Check country location in terms of OECD country risk classification	**X**	**X**	**X**	**X**	**X**	OECD country risk classifications identifies risk because of control measures placed by a government restricting the flow of capital from local currency to foreign currencies. This highlights risks in making payments to external creditors, in the event of natural disasters, war, civil disturbances, etc. Risk Scale based on OECD risk score (1: 1, 2: 2, 3: 3, 4: 4, 5: 5+.)
		• Check country location in terms of IMF world economic data	**X**	**X**	**X**	**X**	**X**	IMF data extracted in terms of population, current account trading balance, GDP and unemployment statistics. Risk scales were assigned as: (1) population (1: 1-9M, 2: 10-19M, 3: 20-29M, 4: 30-39, 5: 40M+); (2) current account trading (1: 20B+, 2: 10-19B+, 3: 0-9B+, 4: -0.1-9B, 5: -20B); (3) GDP (1: 0-99B, 2: 100-299B, 3: 300-399B, 4: 400-499B, 5: 500B+); (4) Unemployment (1: 1-2%, 2: 3-4%, 3: 5-6%, 4: 7-8%, 5: 9%+). Where no data was identified for a given country it was automatically assigned a risk score of 5.
		• Check country location in terms of EU non-cooperative jurisdictions for tax purposes					**X**	Official list of nations, if a country appears on this list, then an automatic risk rating score of 5 was applied.
		• Check country location in terms of EU CAHARA list.	**X**	**X**	**X**	**X**	**X**	Using the official EU CAHRA list, countries were assessed based on the number of regions identified as being a CAHRA, using a risk scale of 1: 1-2, 2: 3-4, 3: 5-6, 4: 7-8, 5: 9+.
		• Check country location in terms of UN Sanctions list					**X**	All countries identified in the UN Security Council Sanctions Regime list were assigned a risk rating of 5.
3.	Supplier identity analysis *(Optional check).*	View company registration information based on the registered location of a supplier. This data would typically identify from either (i) published annual accounts; (ii) contact details on the supplier website; (iii) searching the national companies' registration database where the supplier is located.						Score based on identified data at the supplier level.
		• Is the company registered in the markets it supplies articles to?	**X**	**X**	**X**	**X**		Lower risks occur where suppliers are in the same regions as legal obligations to report information is aligned to local region.
		• Is an offshore registered address used by the supplier?				**X**	**X**	This assessment is looking specifically towards whether a supplier is using an offshore address in a task haven, used to avoid tax payments.
		• Does the supplier have a DUNS number available? – if so request a DUNS number and analyse data on the Dun and Bradstreet website.	**X**	**X**	**X**	**X**	**X**	Identified risk will depend on the outcomes od Dun and Bradstreet report.

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
		• Does the supplier have a CAGE code available? – if so, request the CAGE code and check data.(optional),	**X**	**X**	**X**			CAGE codes are applicable for government and defence contracts.
4.	Financial records analysis *(Optional check).*	View supplier financial accounts to ascertain financial stability of the supplier.						Score based on identified data at the supplier level.
		• Are there any publicly published financial records? (Annual reports).	**X**	**X**	**X**	**X**	**X**	Published accounts should be available via the registered companies house where a supplier is registered. Lack of any public accounts poses a risk
		• Examine financial accounts – has the supplier organisation been profitable in its last financial year?	**X**	**X**	**X**			Identify the supplier financial position in relation to its trading conditions within the marketplace, i.e the overall AD sector growth / decline.
		• Examine financial accounts – has the supplier organisation been profitable over a longer period as shown in financial accounts?			**X**	**X**	**X**	Identify the long-term performance of the supplier
		• Examine any long-term liabilities such as loans and depreciation.			**X**	**X**	**X**	Identify future large scale expenditure which may impact the financial performance of the supplier.
		• Are the financial accounts published to an offshore location?			**X**	**X**	**X**	Check where the accounts are published in case the are placed in known tax havens.
5.	Corporate structure *(Optional check).*	This check would be taken because of (1) and (2), the key is to examine the structure of the supplier organisation to determine any potential risks.						Score based on identifying data at the supplier level and then repeat the process against the supplier's parent organisation.
		• Is the supplier a child organisation of a parent organisation?			**X**			Identify if the supplier is a child or single entity.
		• If a parent / single legal entity type organisation – examine growth investment patterns			**X**	**X**		Identify how the supplier growth patterns have arisen in terms of organic growth or growth by acquisition of other businesses. Assess patterns of selling of business units.
6.	Industry standards	Review supplier quality statements and claims. Perform a search using a web-based search engine, against: (i) [suppler name] ISO 14001; (ii) [suppler name] EASA; (iii) [suppler name] FAA; (iv) [suppler name] CAA						

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
	(Optional check).	• Does the supplier adhere to any quality standards that adhere to management, control and release of design documentation, manufacturing, and product safety?	**X**	**X**	**X**	**X**	**X**	AD companies need to adhere to EASA, CAA or FAA type certifications which place an emphasis on configuration management. Risk score is based on the types of certifications and when they were last assessed.
		• Is the supplier certified against ISO 14001:2015? – if so, how recent was the certification? Were any issues reported?	**X**	**X**	**X**	**X**	**X**	ISO 14001:2015 Environment Management Systems. The risk scale was calculated based: (1) 1: certification taken place in past 12 months; (2) 2: certification undertaken between 13 to 24 months; (3) certification undertaken between over 24 months; (4) certification pending; (5) no certification.
7.	Product Stewardship *(Optional check).*	Review supplier product stewardship statements and claims. Perform a search using a web-based search engine, against [suppler name] product stewardship.						
		• Does the supplier organisation readily identify any product stewardship activities?	**X**	**X**	**X**	**X**	**X**	Product stewardship activities will identify how the supplier organisation performs configuration management, product safety and basic environmental control measures. Risk scores based on identifiable gated reviews; internal review boards; environment aspects assessed; end consumer product safety issues assessed? regular reviews and assessments.
8.	Data protection and Cyber Security *(Optional check).*	Review supplier data protection and cyber security statements and claims. Perform a search using a web-based search engine, against: (i) [suppler name] data protection, and; (ii) [suppler name] cyber security.						
		• Does the supplier adhere to EU GDPR? – how often is the supplier reviewing procedures.	**X**	**X**	**X**	**X**	**X**	EU GDPR applies to data stored in the EU as well as non-EU organisations storing data on EU citizens
		• Does the supplier adhere to US DFARS NIST reporting? – how often is the supplier reviewing procedures (optional).			**X**	**X**	**X**	US DFAR NIST reporting defines data control measures like EU GDPR, but specific US Federal purchases.
9.	Corporate Social Responsibility	Review supplier corporate social responsibility statements and claims. Using either (i) annual published accounts, or (ii) performing search using a web-based search engine, against [suppler name] corporate social responsibility.						Review CSR statements and assess claims

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
	(CSR) *(Optional check).*	• CSR statements available?	**X**	**X**	**X**	**X**	**X**	Risk scores based on clear CSR statements, with proof of investments and change in societal, through to higher risk scores where nothing exists.
		• Does the supplier show adherence to CSR standards?	**X**	**X**	**X**	**X**	**X**	ISO26000 – Social Responsibility / other standards.
		• Does the supplier invest in CSR projects?	**X**	**X**	**X**	**X**	**X**	Risk scores based on clear CSR statements, with proof of investments and change in societal, through to higher risk scores where nothing exists.
		• Has the supplier provided any information on examples of CSR project investment?	**X**	**X**	**X**	**X**	**X**	
		• Has the supplier provided any information CSR project investment governance?	**X**	**X**	**X**	**X**	**X**	
10	Sustainability *(Optional check).*	Review supplier corporate social responsibility statements and claims. Using either (i) annual published accounts, or (ii) performing search using a web-based search engine, against [suppler name] sustainability (this data may appear under CSR section of supplier websites).						
		• Sustainability statements available?	**X**	**X**	**X**	**X**	**X**	Risk scores based on clear sustainability statements, with proof of investments and change in societal, through to higher risk scores where nothing exists.
		• Does the supplier show adherence to sustainability standards?	**X**	**X**	**X**	**X**	**X**	ISO 5004 – Energy Management Systems / others
		• Does the supplier provide any data in relation to UN SDG commitments?	**X**	**X**	**X**	**X**	**X**	Risk scores based on clear sustainability statements, with proof of investments and change in societal, through to higher risk scores where nothing exists.
		• Is the supplier committed to Zero-Waste?	**X**	**X**	**X**	**X**	**X**	
		• Does the supplier provide any statements relating to recycling and use of recycled materials in articles?	**X**	**X**	**X**	**X**	**X**	

#	Area	Criteria examples	Low (L): [1]	Low-Medium (L-M): [2]	Medium (M): [3]	Medium High (M-H): [4]	High (H): [5]	Comments
		• Does the supplier provide any information relation to their carbon footprint?	**X**	**X**	**X**	**X**	**X**	
		• Does the supplier provide any statements relating to their use of Critical Raw Materials?	**X**	**X**	**X**	**X**	**X**	Cross check any supplier declared data in the application against applicable critical raw material lists.
11.	Human Rights, Forced Labour, and Modern Slavery *(Optional check).*	Review supplier human rights statements and claims. Perform a search using a web-based search engine, against: (1) [suppler name] human rights; (2) [suppler name] child labour; (3) [suppler name] forced labour, and; (4) [suppler name] child labour; modern slavery.						Identify issues associated with the supplier in terms of human rights, forced labour and modern slavery.
		• Does the supplier adhere to any human rights standards?	**X**	**X**	**X**	**X**	**X**	Identification of supplier meeting international labour standards. SA 8000 – Human rights. Risk score based on number of incidents and how far in the past.
		• Has the supplier been identified with any child labour issues?	**X**	**X**	**X**	**X**	**X**	Risk score based on number of incidents and how far in the past.
		• Does the supplier have a modern slavery statement?	**X**	**X**	**X**	**X**	**X**	
11.	Fraud, Legal Judgements and Sanctions *(Optional check).*	Review supplier human rights statements and claims. Perform a search using a web-based search engine, against: (1) [suppler name] fraud; (2) [suppler name] legal judgements, and; (3) [suppler name] sanctions;						
		• Has the supplier been associated with any incidents of fraud?	**X**	**X**	**X**	**X**	**X**	Risk score based on number of incidents and how far in the past.
		• Has the supplier been associated with any legal judgements?	**X**	**X**	**X**	**X**	**X**	
		• Has the supplier been associated with any incidents of sanctions?	**X**	**X**	**X**	**X**	**X**	

Appendix 15: SupplierRiskScore Simulated Walkthrough

A simulation of the SupplierRiskScore scores, based on multiple suppliers for the same articles, was extracted from the SupplierRiskAssessment data load template. The steps undertaken in the analysis were as follows:

- Open the SupplierRiskAssessment data load template.
- Save a local copy of the data load template and rename it (as further edits will be needed).
- Highlight all cells in the data load template.
- Home → Sort & Filter → Custom sort.
- **Sort against column E** – Supplied articles.
- The data load template will now be sorted against column E.
- Delete all rows where Column E shows values of **no data** as they pertain to suppliers where no articles were identified as being no articles being provisioned by the supplier.
- Highlight column E → Home → Conditional Formatting → Highlight Cell Values → Duplicate Values.
- The duplicate values in column E will become highlighted.
- Delete all rows that do not appear as highlighted cells in column E, as they relate to individual articles from suppliers which are not duplicated by alternative suppliers.
- Hide columns F to CB.
- The resultant data load template will show articles that are sourced from multiple suppliers with column CC, SupplierRiskScore acting as the main index score.
- The higher the SupplierRiskScore the greater the risk associated with a supplier.
- The resultant sheet SupplierRiskAssessment_Simulated shows articles sourced from multiple suppliers.

	A	B	C	D	E	F	CC
1	Supplier	SupplierName	Country	Asses	SuppliedArticl	ArticleDescription	SupplierRiskSco
2	PAM011	DD Corp	USA	Yes	A102	Unified Hex Hd Bolt HT St. Cad	82
3	PAM017	FDD Aerospace Langfang	Germany	Yes	A102	Unified Hex Hd Bolt HT St. Cad	60
4	PAM022	Wmake Aerospace	France	Yes	A102	Passenger Window Mounts	69
5	PAM011	DD Corp	USA	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	79
6	PAM017	FDD Aerospace Langfang	Germany	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	82
7	PAM022	Wmake Aerospace	France	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	58
8	PAM010	Anext	USA	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	65
9	PAM011	DD Corp	USA	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	58
10	PAM012	Fastners R Us Inc	France	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	55
11	PAM011	DD Corp	USA	Yes	A173	Unified Csk Slot Hd Bolts HT. St. Cad	56
12	PAM012	Fastners R Us Inc	France	Yes	A173	Unified Csk Slot Hd Bolts HT. St. Cad	52
13	PAM010	Anext	USA	Yes	A211	Unified Pan X Rec Hd Bolt HT St. Cad.	64
14	PAM012	Fastners R Us Inc	France	Yes	A211	Unified Pan X Rec Hd Bolt HT St. Cad.	53
15	PAM011	DD Corp	USA	Yes	A59	BA/BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	79
16	PAM017	FDD Aerospace Langfang	Germany	Yes	A59	BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	82
17	PAM022	Wmake Aerospace	France	Yes	A59	BA/BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	57

- The risks associated with suppliers of the same articles can be identified by the SupplierRiskScore, where the lower the value of the SupplierRiskScore identifies a supplier with fewer risks identified.

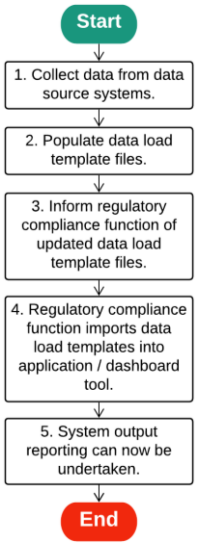
	A	B	C	D	E	F	CC
1	Supplier	SupplierName	Country	Asses	SuppliedArticl	ArticleDescription	SupplierRiskSco
2	PAM011	DD Corp	USA	Yes	A102	Unified Hex Hd Bolt HT St. Cad	82
3	PAM017	FDD Aerospace Langfang	Germany	Yes	A102	Unified Hex Hd Bolt HT St. Cad	60
4	PAM022	Wmake Aerospace	France	Yes	A102	Passenger Window Mounts	69
5	PAM011	DD Corp	USA	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	79
6	PAM017	FDD Aerospace Langfang	Germany	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	82
7	PAM022	Wmake Aerospace	France	Yes	A111	Unified Cl. Tol. Hex Hd Bolt HT. St. Cad	58
8	PAM010	Anext	USA	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	65
9	PAM011	DD Corp	USA	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	58
10	PAM012	Fastners R Us Inc	France	Yes	A113	Unified Mush Head Bolt HT. St. Cad.	55
11	PAM011	DD Corp	USA	Yes	A173	Unified Csk Slot Hd Bolts HT. St. Cad	56
12	PAM012	Fastners R Us Inc	France	Yes	A173	Unified Csk Slot Hd Bolts HT. St. Cad	52
13	PAM010	Anext	USA	Yes	A211	Unified Pan X Rec Hd Bolt HT St. Cad.	64
14	PAM012	Fastners R Us Inc	France	Yes	A211	Unified Pan X Rec Hd Bolt HT St. Cad.	53
15	PAM011	DD Corp	USA	Yes	A59	BA/BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	79
16	PAM017	FDD Aerospace Langfang	Germany	Yes	A59	BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	82
17	PAM022	Wmake Aerospace	France	Yes	A59	BA/BSF Hex Hd Cl. Tol. Bolt HT. St. Cad.	57

Appendix 16: Data Maintenance Activities

This section describes the basic data maintenance activities needed to support the system output reports generated by the application.

Data Load Template Related Activities

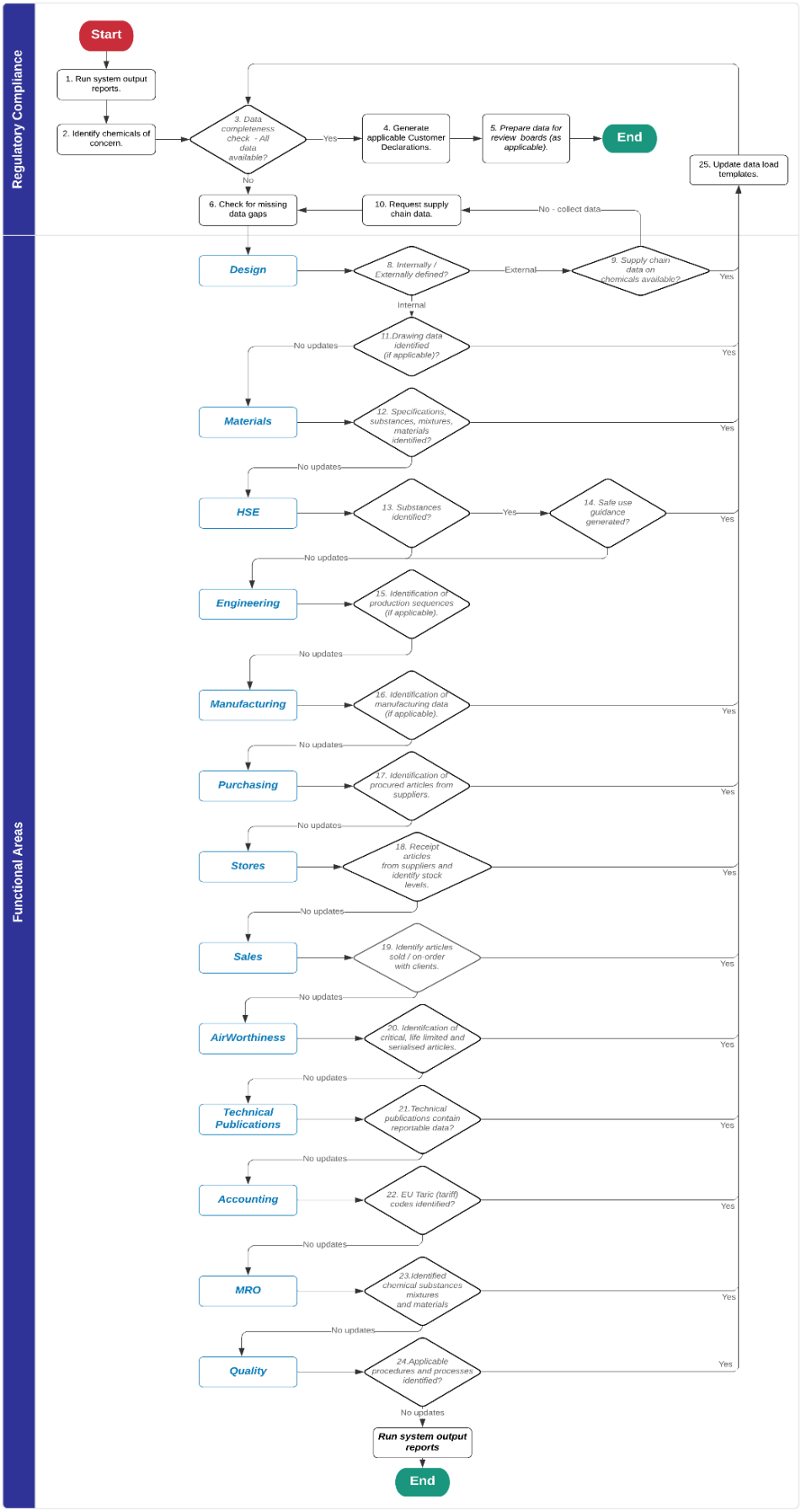
Figure [Appendix Figure 17] depicts the high-level process for data load templates being ingested into the application to create and / or update records in the application.



Appendix Figure 17: Data Load Acting As System Maintenance Process

Data Maintenance: Updating Existing Records

1. Figure [Appendix Figure 18] presents a high-level overview of data load template updating procedures.
2. Relevant data load templates status fields to help denote whether a record needs to be reviewed by an applicable function area.
    a. The database application contains status charts to highlight records that need to be reviewed and updated.
3. Applicable business functions will update data load templates, either with new data, or make changes based on updated information, or a new record being created:
    a. Table [Appendix Table 8] outlines the steps to update existing data records in the data load templates.
    b. Table [Appendix Table 9] outlines the steps to insert new records into the data load templates.



Appendix Figure 18: High-Level Overview of Data Load Template Update Procedures

Appendix Table 8: Update Data Load Templates (By Review Status)

Business function	**Data load template name**	**Update logic**	**Tasks to be undertaken**
HSE	SafeUseGuidance	Identify substances in the template that require action.	Filter on **ReviewStatus,** select records with values of either: (a) Awaiting Review, or; (b) On Hold Awaiting Further Information.
	SubstanceAnalysis	Identify substances in the template that need to be assessed for safety risks.	Filter on **SDSAssessment** select records with values of either: (a) Awaiting assessment of substance within SDS; (b) Awaiting assessment of substance within Specification, or; (c)SDS substance assessed awaiting safe use guidance.
		Identify substances in the template that required safe use guidance to be defined.	Filter on **SUGID** select records with values of TBD.
Materials	Mixture	Identify substances in the template that require action.	Filter on **ReviewStatus**, select records with values of (a) Awaiting Review; (b) Low Priority - Legacy Mixture; (c) Reviewed - More Data Needed from Manufacturer.
	Material		
	SubstanceAnalysis		Filter on **MaterialsAssessment**, select records with values of: (a) Awaiting assessment of substance within SDS, or; (b) Awaiting assessment of substance within Specification.
Design	Drawing	Identify drawings in the template that require action.	Filter on **ReviewStatus**, select records with value of Drawing awaiting review.
Engineering	Engineering	Identify manufacturing process steps in the template that require action.	Filter on **ReviewStatus,** select records with value of Awaiting Review.
Manufacturing	Component	Identify articles in the template that require action.	Filter on **ReviewStatus,** select records with value of Awaiting Review.
	PartNumber		
	Assembly		
Stores	Stores	Identify records in the template that require action.	Filter on **ReviewStatus**, select records with value of: (a) Awaiting Review, or; (b) Initial Review – Check Data.
Accounting	SCIPEUTaricCodes	Identify records in the template that require action.	Filter on **Status** select records with value of: (a) Awaiting Review; (b) On-Hold Awaiting Further Information.
MRO	MRO	Identify records in the template that require action.	Filter on **ReviewStatus**, select records with value of: (a) Awaiting Review, or; (b) Review On Hold.
Technical Publications	TechnicalPublications	Identify records in the template that require action.	Filter on **CreatedBy**, select records with NULL values.
Regulatory compliance	SupplierDeclaration	Identify records in the template that require action.	Filter on **SupplierDeclarationStatus**, select records with value of Initial

Business function	Data load template name	Update logic	Tasks to be undertaken
			Supplier Declaration Requested (denotes a risk of not knowing if a supplied article is compliant).
	PositiveDeclaration	Identify records in the template that require action.	Filter on **ReviewStatus**, select records with value of Positive Declaration Requested (denotes a risk of not knowing if a supplied article is compliant).
	SupplierRiskAssessment. SupplierRiskAssessment_Simulated		Filter on **Assess**, select records with value of No.

Appendix Table 9: Update Data Load Templates (New Data)

Task	Data load template name	Tasks to be undertaken
New article(s).	Assembly PartNumber Component Drawing; Mixture; Material; SubstanceAnalysis; SupplierDeclaration; DetailedDeclaration; PositiveDeclaration.	• Insert new record in Assembly data load template (if applicable) set **ReviewStatus** value to Awaiting Review. • Insert new record in PartNumber data load template (if applicable) set **ReviewStatus** value to Awaiting Review. • Insert new record in Component data load template (if applicable) set **ReviewStatus** value to Awaiting Review. • Review processes shall identify: ○ Internally defined, review existing records inserting new records (as applicable) with **ReviewStatus** value set to Awaiting Review: ▪ Lower-level part numbers PartNumber. ▪ Lower-level components Component. • Drawings, mixtures and materials (Drawing; Mixture; Material) • Substance analysis identification of: (i) substance names; (ii) substance being reportable (SubstanceAnalysis); (iii) safe use information in relation to the chemical substance (SafeUseGuidance). ○ Supply chain sourced / defined: ▪ Request data from supply chain SupplierDeclaration. ▪ Receipt and review data on: (i) supply chain use of hazardous chemicals; (ii) existing ECHA SCIP notifications; (iii) use of any authorisations and exemptions; (iv) safe use guidance (DetailedDeclaration). ▪ Request Positive Declarations from suppliers having reported chemicals of concern in a detailed declaration to ascertain potential risks (PositiveDeclaration).
Generate customer declarations.	SupplierDeclaration; PositiveDeclaration; SubstanceAnalysis; CustomerDeclaration	• Review system output reports for Article definitions (SubstanceAnalysis). • Review supplier declared data (SupplierDeclaration, PositiveDeclaration). • Update CustomerDeclaration table, based on internally articles and supply chain procured articles.
Generate / updates to technical publications.	CustomerDeclaration	• Assume CustomerDeclaration identifies to the technical publications function, reportable chemical substances. • The table should act as an indirect trigger to the HSE function, to ensure applicable safe use guidance in relation to a chemical substance needs to be generated.
Create / updates to regulatory substance lists.	DSLReference; DetailedDSL.	• Update DSLReference with new records for each new DSL / RSL • Create / update substance records against an RSL via DetailedDSL.
Create / updates to chemical inventory list.	ChemicalSubstanceInventory	• Periodically **physically audit** substances, mixtures, materials and a and materials held in manufacturing areas.

Task	Data load template name	Tasks to be undertaken
		• Record latest stock information in Stores **overwriting any existing data.**
Create / updates to stock records.	Stores	• Periodically **physically audit** substances, mixtures, materials and a and materials held in stores area. • Record latest stock information in ChemicalSubstanceInventory **overwriting any existing data**.
Create / updates to sales order book data.	SalesGDPR; SalesForwardLoad.	• **Periodically update** future sales order data SalesForwardLoad**.**
Create / updates to purchase order book data.	PurchasingForwardLoad; SupplierGDPR	• **Periodically update** future purchase order data (PurchasingForwardLoad)**.**
Create / updates to ECHA SCIP related data	SCIPEUTaricCodes; SCIPMaterialCategories; SCIPMixtureCategories.	• Download latest values from ECHA website. • Extract records and **update where new records identified in** SCIPEUTaricCodes, SCIPMaterialCategories and SCIPMixtureCategories**, set applicable status values to Awaiting Review.**

Appendix 17: Delphi Study 2: Conceptual Blockchain Model

This section presents the feedback comments from Delphi Study 2, the conceptual blockchain. The outputs from this Delphi study did not feed into the design of the data model, and therefore the results have been presented within this appendix.

Aim of Delphi Study

An initial investigation into blockchains being utilized in the context of supply chain chemical substance reporting was investigated (Takhar and Liyanage, 2018b). This Delphi study further investigated: (1) what chemical substance information is available in relation to purchased articles?; (2) what are the key methods in which this information is defined, requested, and supplied?; (3) why a blockchain might aid the supply chain chemical substance reporting data collection process. The name designated to the proposed blockchain is 'Supply Chain Chemical Substance Reporting' (SCCSR).

Duration, response rates and respondent industry sectors

Three rounds of Delphi surveys were conducted between November 2018 until March 2019. The location of the online surveys and response rates are shown in Table [Appendix Table 10].

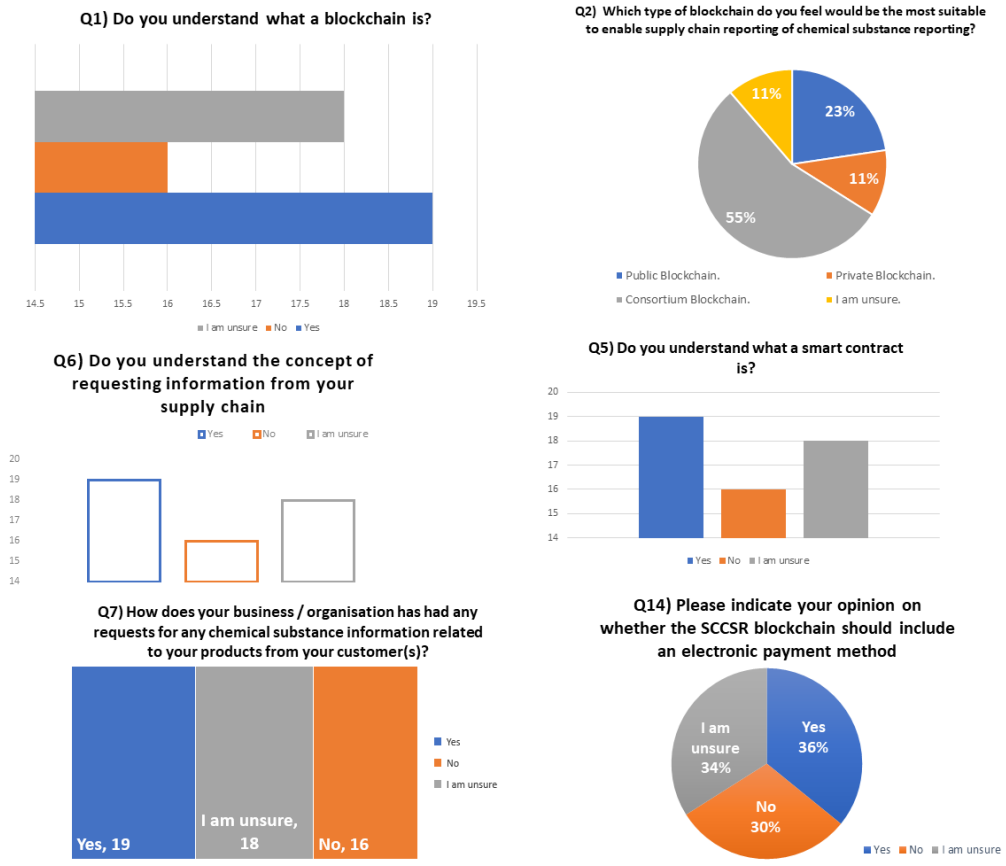
Appendix Table 10: Delphi study 2: survey locations and response rates

Round	Survey Link	Invited participants	Completed responses	Incomplete responses
1	Delphi Study 2 – Round 1	76	52 (68.42%)	3 (3.95%)
2	Delphi Study 2 – Round 2	52	42 (80.77%)	5 (9.61%)
3	Delphi Study 2 – Round 3	42	21 (50%)	2 (4.76%)

The industry sectors respondents worked within were: (1) educational establishment (35.3%); (2) producer of articles (19.61%); (3) importers of articles (17.64%); (4) retailer / distributor of articles (7.84%); (5) consumer of articles (7.84%); (6) other: consultant, lawyer, research institute (5.89%); (7) Original Equipment Manufacturer (OEM) - the article designer / technical authority (5.88%). The age groups respondents belonged to were: (1) 26-35 (27.45%); (2) 36-45 (27.45%); (3) under 25 (21.57%); (4) unwilling to disclose (9.80%); (5) 46-55 (7.84%); (6) 56-65 (1.96%).

8.6.1 Delphi study 2: Round 1 Findings

This round of the Delphi study aimed to provide respondents with some conceptual foundations relating to blockchains. Figure [Appendix Figure 20] shows a summary from the short form questions presented in this round of the Delphi study.



Appendix Figure 19: Delphi study 2: Round 1 summary of short form questions

Table [Appendix Table 11] details a summary of the multiple answer questions with the top 5 answers identified by respondents.

Appendix Table 11: Delphi study 2: Round 1 long form question summary

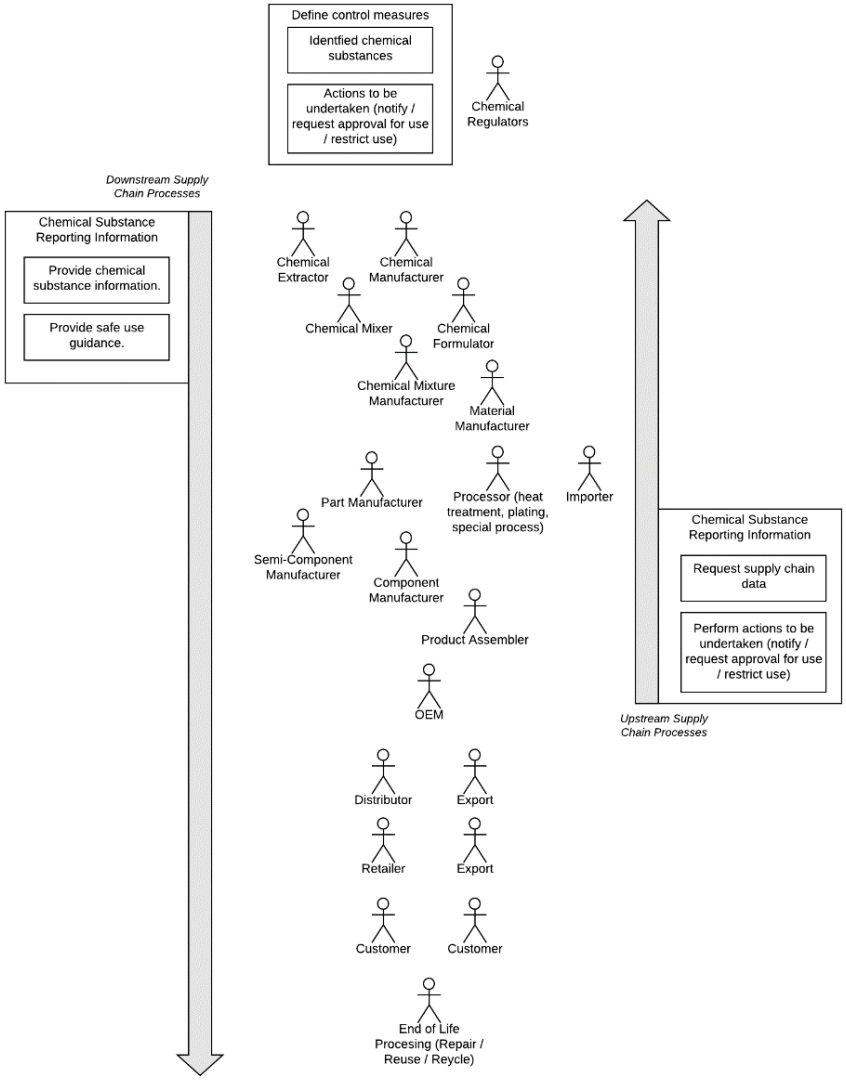
#	Question logic	Top 5 Answers
3.	Respondents presented with several statements regarding potential use of blockchains and a Likert scale between 1 to 7 (1 lacks potential, 7 strong potential).	• Record transaction, 7 (52.9%); • Enable supply chain data transparency, at 7 (45.1%); • Automate payments, 7 (43.1%); • Record details of asset ownership, 7 (39.2%); • Enable collaborative data exchange between different parties, 7 (37.3%).
4.	Respondents with several statements regarding potential inhibitors to the use of blockchains and a Likert scale between 1 to 5 (1 strongly disagree, 5 strongly agree).	• The supply chain my organisation / industry operates within is highly complex making the blockchain process difficult to implement, 3 (39.2%); • Lack of trust in blockchains, 4 (33.3%); • There is a lack of visibility of blockchains within my organisation, 4 (33.3%); • Fears over transmitting data using IoT devices, 3 (33.3%); • Concerns over potential Intellectual Property loss, 3 (33.3%).
8.	respondents presented with several statements regarding potential inhibitors to the use of blockchains and a Likert scale between 1 to 4 (1 lack any information, 5 strongly agree).	• Products you design and have manufactured externally from supply chain, 1 (35.3%); • Products you design and manufacture internally, 1 (29.4%); • Products you procure from a supply chain, 1 (29.4%).
9.	Respondents presented with several statements regarding supply chemical substance reporting currently being conducted within their organisations.	• No data is being requested from the suppliers (35.29%); • A basic risk assessment check is done against which supplier products are likely to contain substances of concern, then based on the outcome, suppliers are then requested to provide substance information (29.41%); • Suppliers are requested to provide substance information as part of a contract (29.41%); • Suppliers provide the information but there is no contractual obligation to provide the information (21.57%); • Use of third-party solution providers to perform the request and collation of data, we act on the results from the solution providers (15.69%).
10.	Respondents asked to select statements regarding the methods currently used to collect supply chemical substance reporting information..	• No data is being requested from the suppliers, (39.22%); • Spreadsheets are used to request data, (19.61%); • Word processed documents are used to request data, (13.73%); • XML forms are used to request data, (11.76%); • PDF documents are used to request data, (9.80%);
11.	Respondents asked to select statements regarding how supply chain chemical substance reporting data is being processed within organisations.	• The information is stored electronically in a bespoke internal IT system (33.33%); • I am not an expert in this area (11.76%); • No data is being stored (11.76%); • The information is stored electronically in a standard ERP type IT system (7.84%); • The information is printed off and stored manually (3.92%).
12.	Respondents asked to select statements relating data exchange methods used to support supply chain substance reporting.	• No data is being requested from the suppliers (35.29%); • Emails are used to exchange files (23.53%); • Files uploaded via an HTTPS location (13.73%); • Files uploaded via an On-line portal (11.76%); • others (11.25%).
13.	Respondents asked to identify the amount of FTE resources	• No resources are allocated directly for this task (37.25%); • Not aware of the actual data (33.33%);

#	Question logic	Top 5 Answers
	allocated to performing supply chain chemical substance reporting.	• About 3 FTEs (9.80%); • Less than 1/2 a FTE (5.88%); • Greater than 5 FTEs (5.88%).

The closing question within this round related to asking respondents if they felt the SCCSR blockchain should include a payment method, the responses were: (1) Yes - an electronic payment should be included within the blockchain design (37.25%); (2) I am unsure (37.25%); (3) No - an electronic payment should not be included within the blockchain design (25.49%). The main respondent feedback comments in this round of the Delphi study pertained to the respondents stating that they had limited knowledge of the questions being posed, which may be attributable to the fact that the respondents were from a mix of industry and academia.

8.6.2 Delphi study 2: Round 2 Findings

This round of the Delphi study expanded on the previous round by presenting respondents with conceptual definitions to be used within the SCCSR blockchain. The first question presented respondents with a definition of a supply chain then asked to select applicable responses, the highest number of responses were as follows: (1) include as is, within the blockchain model (69.86%); (2) drop and do not use within the blockchain model (29.73%); (3) include with edits, in the blockchain model (5.41%).



Appendix Figure 20: Conceptual SCCSR blockchain: Supply chain definition

The second question presented respondents with a definition of supply chain chemical substance reporting as shown in Figure [Appendix Figure 21] and then asked to select applicable responses, the highest number of responses were as follows: (1) include as is, within the blockchain model (67.57%); (2) drop and do not use within the blockchain model (32.43%).

Respondent feedback comments: (1) Respondent F: *Consider including the following criteria as add-on: (a) each product supply implies a distinct set of actors (it is not mandatory to have all the actors); (b) each product supply implies a distinct flow of transformations (it is not mandatory to have all the parts - they are actually quite different products); (c) actors can be played by the exact same organisation - for performance issues - only include ownership in the blockchain when the product or service leaves the*

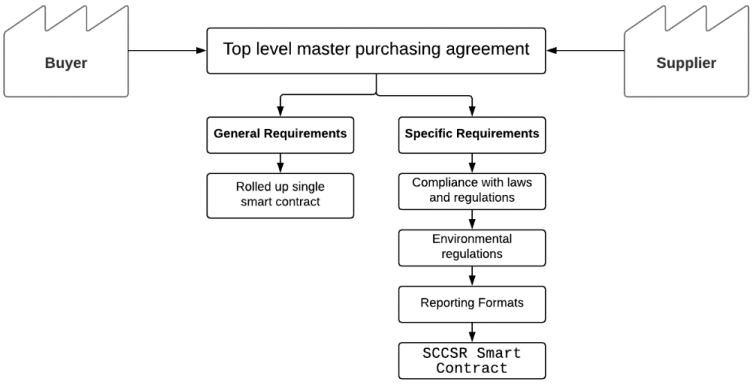
actual organisation (regardless of the role they play) >> the product remains of the last known (a registered) actor. Author comment: accept comments and adjust final design to reflect comments.

(2) Respondent G: *Transformations (of the products) are the backbone that should be included in the blockchain - register the transformations suffered by a product (the type of transformation and the end result).* Author comment: accept comments and adjust final design to reflect comments.

The third question was based on round 1 responses, respondents were presented with a view on consortium blockchain and asked to select applicable responses, the highest number of responses were as follows: (1) include as is, within the blockchain model (64.86%); (2) drop and do not use within the blockchain model (29.73%); (3) include with edits, in the blockchain model (5.41%).

Respondent feedback comments: (1) Respondent A: *typically scale better than public blockchains. - ...may be mutable. Certainly, a rollback capability implies the ability to edit the blockchain by rolling back to an earlier node and editing or replaying subsequent transactions. - ...could use an arbitrary consensus algorithm and could include a governance mechanism to change the consensus rules.* Author comment: accept comments and adjust final design to reflect comments.

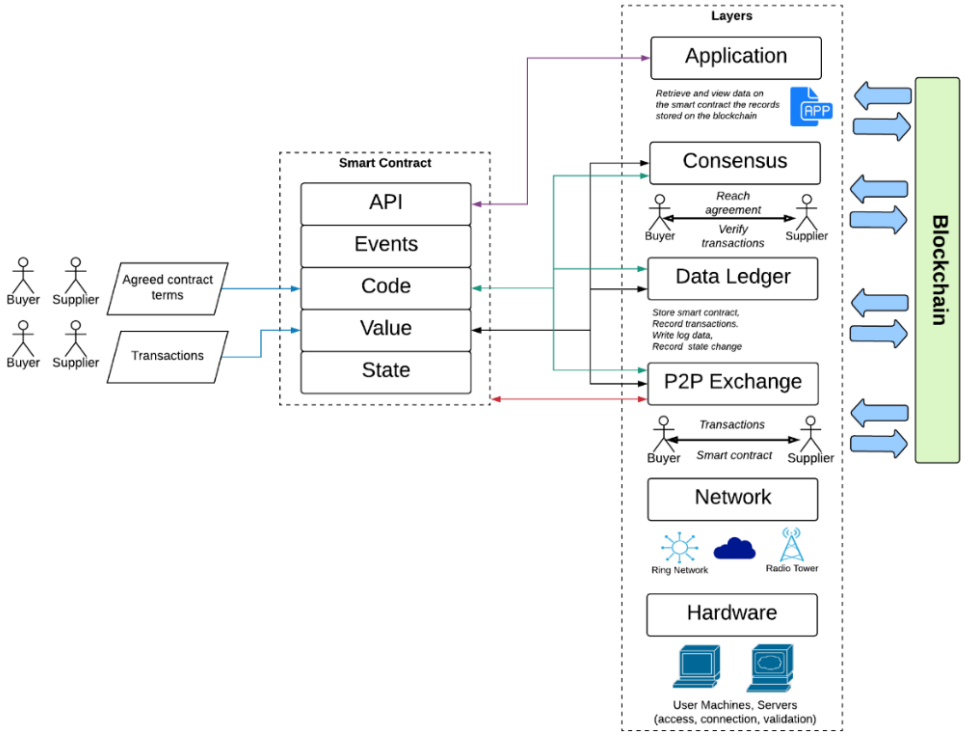
The third question presented respondents with an overview of a master purchasing agreement and then asked to select applicable responses, the highest number of responses was for, include as is, within the blockchain model (64.86%). The fourth question presented respondents with a system context diagram as shown in Figure [Appendix Figure 22] and then asked to select applicable responses, the responses were: (1) include as is, within the blockchain model (64.86%); (2) drop and do not use within the blockchain model (27.03%); (3) include with edits, in the blockchain model (8.11%).



Appendix Figure 21: Conceptual SCCSR blockchain: System context diagram

Respondent feedback comments: (1) Respondent B: *Consider including the information regarding the fact that every contract has always the general requirements and then a specific set of sub smart contracts. The diagram might be understood as the contract having one type (generic) or the other (specific), and not both*. Author comment: accept comments and adjust final design to reflect comments.

The fifth question presented respondents with conceptual SCCSR blockchain smart contract as shown in Figure [Appendix Figure 23] and then asked to select applicable responses, the highest number of responses was for, include as is, within the blockchain model (70.27%).



Appendix Figure 22: Conceptual SCCSR blockchain: SCCSR Smart Contract

The closing question in this round, asked the same question as in Round 1 regarding whether the SCCSR blockchain should include an electronic payment method, and then asked to select applicable responses, the highest number of responses was for, include as is, within the blockchain model (54.05%).

8.6.3 Delphi study 2: Round 3 Findings

The final round in the Delphi study presented updated designs for the SCCSR blockchain. The first question presented respondents with a definition of a products and supply chains, and then asked to select applicable responses, the highest number of responses was as follows: (1) include as is, within the blockchain model (66.67%); (2) I am unsure (23.81%); (3) drop and do not use within the blockchain model (9.52%).

Respondent feedback comments: (1) Respondent C: *Some products are divisible and fungible and may be transformed partially. There should be a provision to register in the blockchain the division of an amount of product into smaller amounts. Similar for recycled products. A complex product may be recycled into amounts of simpler components, each with different quality and suited for different purposes*. Author comment: accept comments and adjust final design to reflect comments.

The second question presented respondents with a definition on the need for chemical substance reporting and then asked to select applicable responses, the highest number of responses was for, include as is, within the blockchain model (57.14%).

The third question presented respondents with a series short statements relating to blockchain concepts and then asked to select applicable responses, the highest number of responses as follows: (1) Proof of Work (PoW): adopt in the blockchain model (33.33%); (2) Proof of Stake (PoS): adopt in the blockchain model (33.33%); (3) Proof of Elapsed Time (PoET): adopt in the blockchain model (33.33%); (4) Practical Byzantine Fault Tolerance (PBFT): adopt in the blockchain model (28.6%); (5) Federated Byzantine Agreement (FBA): consider in the blockchain model (33.33%); (6) Proof of Authority (PoA): consider in the blockchain model (33.33%).

The fourth question presented respondents with a definition of a smart contract and then asked to select applicable responses, the highest number of responses for, include as is,

within the blockchain model (57.15%). The fifth question presented respondents with a definition of a master purchasing agreement and then asked to select applicable responses, the highest number of responses for, include as is, within the blockchain model (52.38%).

The closing question asked respondents to provide preferences in terms of using different blockchain types under the SCCSR blockchain, the highest number of responses for: (1) public blockchain: (a) I am unsure (47.6%); (2) permissioned (private) blockchain: (a) I am unsure (52.4%); (3) consortium blockchain: (a) I am unsure (52.47%).

Further research

Following the completion of Delphi study 2, the author has engaged with: (1) United Nations Environmental Program to discuss potential use of such a blockchain to trace and identify the manufacture, movement and shipment of highly controlled hazardous substances; (2) blockchain providers to examine how the SCCSR blockchain might further be developed this has resulted in the author reviewing the possibility of including a token based reward system, in lieu of a cryptocurrency payment system, where actors within the blockchain manufacturers, data providers receive tokens after data is validated, the concept being the more tokens awarded the greater the assumed accuracy / completion of smart contract terms; (3) applicable respondents from the AD sector were engaged to provide examples of generic product types, to enable a representative set of test data to be generated to test the final data model and output reporting.

Appendix 18: Detailed Technical Design Document

The Technical Design Documentation generated as part of this research study is stored on OneDrive file locations as shown in Table [Appendix Table 12]:

Appendix Table 12: Application Design and Implementation Details

Name	Folder name	Folder contents
Design Documentation.	Design_Documentation.	Top-level folder containing design documentation.
	01_Requirements_Register.	Research study requirements register.
	02_Risk_Register.	Research study risk register.

	03_Data_Model.	Research study data model diagrams:
		• High-level data model overview:
		  ○ Substance level tables.
		  ○ Article level tables.
		  ○ Supplier level tables.
		  ○ Customer level tables.

Name	Folder name	Folder contents
		○ Other tables.
	04_UI_Storyboards (database).	Application user interface mock-up diagrams: • MainMenu: ○ HSE Function. ○ Materials Function. ○ Design Function. ○ Engineering Function. ○ Purchasing Function. ○ Sales Function. ○ Quality Function. ○ Manufacturing Function. ○ Stores Function. ○ Accounting Function. ○ Airworthiness Function. ○ MRO Function. ○ Tech Pubs Function. ○ Regulatory Compliance Function. • Change Log.
Application Software.	Database.	Top-level folder containing application software.
	01_Dataset_Templates.	Initial blank dataset templates created in MS-Excel format.
	02_WIP_Source_Datafiles.	Initial blank dataset templates populated with test data prior to the application development process taking place.
	03_Supplemental_Analysis_Files.	Initial analysis files used to support the creation of test data. Key files were: (i) MasterBOM, used to generate the master BOM; (ii) OrderScheduler, used to calculate the estimated dates for articles based on defined customer delivery dates; (iii) StakeholderList, used to list potential external stakeholders.
	04_WIP_Database_versions.	WIP versions of database application.
	00_WIP_Dashboard_versions.	WIP versions of dashboard application.
	05_Dataset_One.	Data load template files with test data as used in the WIP versions of the application from 0.07 to 0.14.
	06_Dataset_Two.	Data load template files with test data as used in the WIP versions of the application from 0.15 to 0.16.
	07_Dataset_Three.	Data load template files with test data as used in the WIP versions of the application from 0.17 to 0.28.
	08_Reference_Tables.	Detailed data templates used to compile data from multiple sources, used to define initial data structure and develop data load templates.
	09_Dataset_Four.	Data load template files with test data as used in the WIP versions of the application from 0.29 to 0.30.
	05_Dashboard_Data_Load_Templates.	Latest dashboard data load templates.
	10_Blank_Template_Files_Released.	The latest released versions of the data load template files used to load data in an .xls format, used from application version 0.31 onwards.

Name	Folder name	Folder contents
	11_Latest_Database_Released.	Latest released version of the database application and pre-populated data load template files follow Configure test template files within the application.mp4 to install and configure within the application.
	07_Latest_Dashboard_Released.	Latest released version of the dashboard application. Run the dashboard online or via a local copy where the data load templates will need to be configured.
	13_Other_Tools.	Tools developed early on in PhD research to aid companies to perform the calculation of substances on finished articles. Substance Mass Calculator Tool and User Guide.
Software Testing Documentation.	07_Testing_Documentation.	Top-level folder: Generated based on requirements being tested and the defined acceptance criteria defined in the requirements documentation.
	System test document (database). System test document (dashboard).	Test use cases to ensure system behaviour is as expected following any changes undertaken. Test document records use case pass / fail, with defects registered accordingly.
	System testing defect report (database).	Register of defects identified because of system testing with remedial actions identified.
	System testing defect report (dashboard).	Register of defects identified because of system testing with remedial actions identified.
User related documentation.	12_Latest_User_Guide_Released (database).	User Guide [*available from with the application*]. Application version number should match the version of the user guide.
	03_User_Guide (dashboard).	Dashboard application user guide.
	06_Video_Walkthroughs.	MP4 walkthrough guides, referenced in User Guide and System Test Document: • Configure test template files within the Application. • Run HSE function reporting. • Run Materials function reporting. • Run Design function reporting. • Run Engineering function reporting. • Run Purchasing function reporting. • Run Sales function reporting. • Run Quality function reporting. • Run Manufacturing function reporting. • Run Stores function reporting. • Run Accounting function reporting. • Run Airworthiness function reporting. • Run MRO function reporting. • Run Technical Publications function reporting. • Run Regulatory Compliance function reporting. • View User Guide. • View Change Log.

Name	Folder name	Folder contents
		• Quit Application. • Discussion of further design enhancements that can be applied by an end user.
Requirement's validation documentation.	**Requirement's** traceability matrix	A validation task was undertaken upon completion of the initial software development cycle to ensure all the framework requirements defined in the Research study requirements register are traceable in the implemented design, using the requirements traceability matrix.

Appendix 19: Substance Mass in Article Calculations (Data Load Templates)

Chemical regulation substance lists assume different threshold values for a given chemical substance, which then trigger potential substance reporting obligations. Additionally, several chemical regulations require specific notifications to a regulator, where a given chemical substance, has been identified as being consumed on its own, within a mixture, material, or article, above a nominal 1 ton per ton per annum threshold level. To aid the analysis, the data load templates were updated to include the substance mass calculation to support these reporting obligations using custom MS-Excel formulas created by the author.

Substance Mass Value Within a Mixture or Material

This method assumes a simple calculation of a chemical substance within a mixture or material. Figure [Appendix Figure 24] depicts a basic calculation to determine the amount of a chemical substance being consumed in a mixture or material form.

$$\frac{\text{(a) \% Amount of a chemical substance [}\textit{Name, CAS, EC}\text{] contained within a supplied mixture / material.}}{\text{(b) Amount of a supplied mixture / material consumed within the manufacture of a single article [}\textit{Finished product, assembly, part number, component, etc}\text{].}} = \text{(c) Estimated amount of chemical substance [}\textit{Name, CAS, EC}\text{] consumed.}$$

Appendix Figure 23: Estimated chemical substance being consumed in mixture / material form

This calculation method was applied as follows:

2. Calculation of *GramWeightValue*:
    (i) User defined UoM value (mg, g, kg, ml, ltr).
    (ii) User defined QtyUsed value for mixture or material.

(iii) Conversion of UoM + QtyUsed based on:
   i. mg value into g weight based on dividing mg value by 1000.
   ii. ml value into g weight assumed to be based on a 1:1 conversion rate into a g value.
   iii. kg value into g weight based on taking a kg value and then multiplying by 1000.
   iv. ltr value into g weight based on taking a ltr value and then multiplying by 1000.

3. Calculation of *QtyMixMin*:

   (i) User defined Min value.
   (ii) GramWeightValue divided by 100 multiplied by Min value.

4. Calculation of *MinTon*:

   (i) Conversion of QtyMixMin as g value into a ton value with 6 decimal spaces.

5. Calculation of *SumMinTon*:

   (i) Multiplication of MinTon value by the number of mixtures, materials or articles supplied.

6. Calculation of *QtyMixMax*:

   (i) User defined Max value for a substance in a mixture or material.
   (ii) GramWeightValue divided by 100 multiplied by Max value.

7. Calculation of *MaxTon*:

   (i) Conversion of QtyMixMax as g value into a ton value with 6 decimal spaces.

8. Calculation of *SumMaxTon*:

   (i) Multiplication of MaxTon value by the number of mixtures, materials or articles supplied.

This calculation method was defined against SubstanceAnalysis and DetailedDeclaration tables. The calculation method allows for determination of whether a given chemical of concern is being consumed within articles at a greater than 1 ton per annum threshold level which may then invoke the need to perform additional regulatory reporting obligations.

Estimated Amount of a Chemical Substance Consumed Within an Article

This method is assumed to be utilized outside of the application by the materials function to determine whether a given chemical substance appears on a finished article at greater than 0.1% w/w threshold value. Figure [Appendix Figure 25] depicts a basic calculation method.

$$\frac{\text{(c) Estimated amount of chemical substance [}\textit{Name, CAS, EC}\text{] consumed.}}{\text{(d) Weight of the article [}\textit{Finished product, assembly, part number, component, etc}\text{] containing the chemical substance.}} = \text{(e) Amount of chemical substance [}\textit{Name, CAS, EC}\text{] in relation to the article.}$$

Appendix Figure 24: Estimated Amount of a Chemical Substance Consumed Within an Article

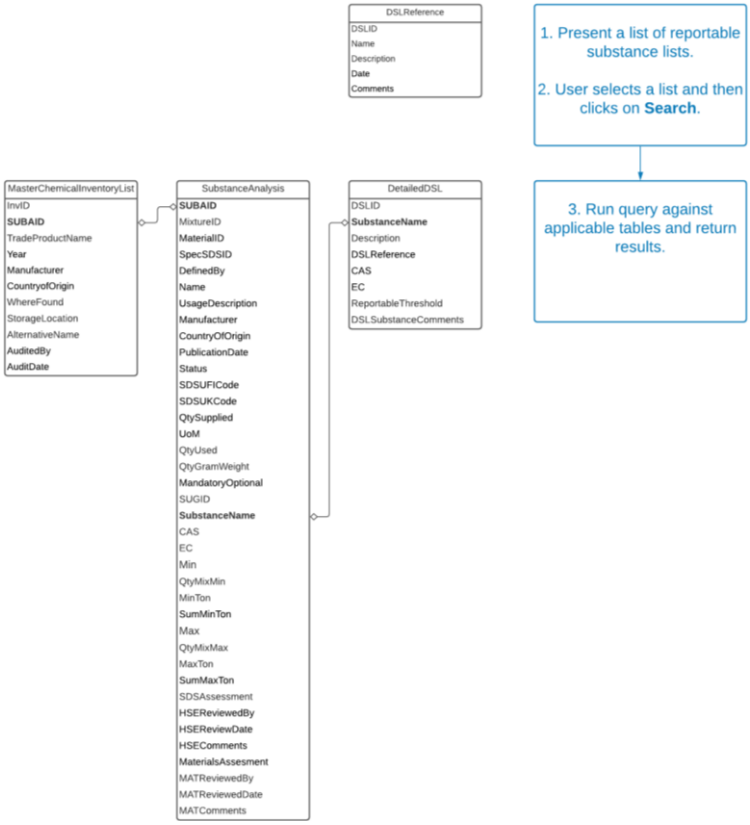
The assumption is that this type of calculation method, can be utilised by both the: (i) internal materials function, and; (ii) a supplier to calculated if a given chemical substance, remains on a finished article at greater than 0.1% w/w threshold level.

Appendix 20: System Output Reports (SQL Statements)

The following sections present a representative sample of the system output reports generated within the application in terms of using standard SQL statements to query tables and return results.

Search Example (1): Search Against a Selected Substance List

The SQL statements are presented in two distinct sections as shown in Figure [Appendix Figure 25] and described below:



Appendix Figure 25: Search Records Against Selected Substance List

Return a List of Substance Lists

The SQL query statement for this list is generated by querying the DSLReference table is shown below:

```
SELECT DSLReference.Description
FROM DSLReference
ORDER BY DSLReference.Description;
```

Return a List of Records

Extending on from the previous SQL query statement, this query returns records related to the selected substance list selected by a user. The SQL query statement for this list is generated by querying the *DetailedDSL*, *SubstanceAnalysis* and related *SourceTable* is shown below:

```
SELECT MasterChemicalInventoryList.InvID, MasterChemicalInventoryList.SUBAID,
MasterChemicalInventoryList.TradeProductName, MasterChemicalInventoryList.Year,
MasterChemicalInventoryList.CountryofOrigin, MasterChemicalInventoryList.WhereFound,
MasterChemicalInventoryList.StorageLocation, MasterChemicalInventoryList.Manufacturer,
SubstanceAnalysis.SubstanceName, SubstanceAnalysis.CAS, SubstanceAnalysis.EC,
SubstanceAnalysis.QtyMixMin, SubstanceAnalysis.MinTon, SubstanceAnalysis.Max,
SubstanceAnalysis.QtyMixMax, SubstanceAnalysis.SumMinTon, SubstanceAnalysis.MaxTon,
SubstanceAnalysis.SumMaxTon, DetailedDSL.Description
FROM (MasterChemicalInventoryList INNER JOIN SubstanceAnalysis ON
MasterChemicalInventoryList.SUBAID = SubstanceAnalysis.SUBAID) INNER JOIN DetailedDSL ON
SubstanceAnalysis.SubstanceName = DetailedDSL.SubstanceName
WHERE (((DetailedDSL.Description)=[Forms]![frmHSEChemicalInventory]![cmbRegSelect]));
```

The query is repeated in several locations within the application, as shown in Table [6-7], where the applicable values for the *SourceTable* are shown.

Search Example (2): Search Against a Trade / Product Name

A search string is enabled within the application to allow a user to enter a trade / product name (*cmbTradeName*) as a search string and then click on the search button to initiate the actual search. Once the search has been initiated, the SQL query statement, shown below, is run to return those records which precisely match the trade / product name.

```
SELECT MasterChemicalInventoryList.InvID, MasterChemicalInventoryList.SUBAID,
MasterChemicalInventoryList.TradeProductName, MasterChemicalInventoryList.Year,
MasterChemicalInventoryList.CountryofOrigin, MasterChemicalInventoryList.WhereFound,
MasterChemicalInventoryList.StorageLocation, MasterChemicalInventoryList.Manufacturer,
SubstanceAnalysis.SubstanceName, SubstanceAnalysis.CAS, SubstanceAnalysis.EC,
SubstanceAnalysis.QtyMixMin, SubstanceAnalysis.MinTon, SubstanceAnalysis.Max,
SubstanceAnalysis.QtyMixMax, SubstanceAnalysis.MaxTon, DetailedDSL.Description,
SubstanceAnalysis.SumMaxTon, SubstanceAnalysis.SumMinTon
FROM MasterChemicalInventoryList INNER JOIN (SubstanceAnalysis INNER JOIN DetailedDSL ON
SubstanceAnalysis.SubstanceName = DetailedDSL.SubstanceName) ON
MasterChemicalInventoryList.TradeProductName = SubstanceAnalysis.Name
WHERE (((MasterChemicalInventoryList.TradeProductName) Like "*" &
[Forms]![frmHSEChemicalInventory]![cmbTradeName]));
```

The query is repeated in several locations within the application, as shown in Table [6-7], where the applicable values for the *SourceTable* are shown.

Search Example (3): Search Against a Chemical Substance Name

A search string is enabled within the application to allow a user to enter a chemical substance name (*cmbSubstanceName*) as a search string and then click on the search button to initiate the actual search. Once the search has been initiated, the SQL query statement, shown below, is run to return those records which precisely match the chemical substance name.

```
SELECT MasterChemicalInventoryList.InvID, MasterChemicalInventoryList.SUBAID,
MasterChemicalInventoryList.TradeProductName, MasterChemicalInventoryList.Year,
MasterChemicalInventoryList.CountryofOrigin, MasterChemicalInventoryList.WhereFound,
MasterChemicalInventoryList.StorageLocation, MasterChemicalInventoryList.Manufacturer,
SubstanceAnalysis.SubstanceName, SubstanceAnalysis.CAS, SubstanceAnalysis.EC,
SubstanceAnalysis.QtyMixMin, SubstanceAnalysis.MinTon, SubstanceAnalysis.Max,
SubstanceAnalysis.QtyMixMax, SubstanceAnalysis.MaxTon, DetailedDSL.Description
FROM (MasterChemicalInventoryList INNER JOIN SubstanceAnalysis ON
MasterChemicalInventoryList.SUBAID = SubstanceAnalysis.SUBAID) INNER JOIN DetailedDSL ON
SubstanceAnalysis.SubstanceName = DetailedDSL.SubstanceName
WHERE (((SubstanceAnalysis.SubstanceName)=[Forms]![frmHSEChemicalInventory]![cmbSubstanceName]));
```

The query is repeated in several locations within the application, as shown in Table [6-7], where the applicable values for the *SourceTable* are shown.

Search Example (4): Search Against a CAS Number

A search string is enabled within the application to allow a user to enter a CAS number (*cmbCAS*) as a search string and then click on the search button to initiate the actual search. Once the search has been initiated, the SQL query statement, shown below, is run to return those records which precisely match the CAS number.

```
SELECT MasterChemicalInventoryList.InvID, MasterChemicalInventoryList.SUBAID,
MasterChemicalInventoryList.TradeProductName, MasterChemicalInventoryList.Year,
MasterChemicalInventoryList.CountryofOrigin, MasterChemicalInventoryList.WhereFound,
MasterChemicalInventoryList.StorageLocation, MasterChemicalInventoryList.Manufacturer,
SubstanceAnalysis.SubstanceName, SubstanceAnalysis.CAS, SubstanceAnalysis.EC,
SubstanceAnalysis.QtyMixMin, SubstanceAnalysis.MinTon, SubstanceAnalysis.Max,
SubstanceAnalysis.QtyMixMax, SubstanceAnalysis.MaxTon, SubstanceAnalysis.SumMinTon,
SubstanceAnalysis.SumMaxTon, DetailedDSL.Description
FROM (MasterChemicalInventoryList INNER JOIN SubstanceAnalysis ON
MasterChemicalInventoryList.SUBAID = SubstanceAnalysis.SUBAID) INNER JOIN DetailedDSL ON
SubstanceAnalysis.CAS = DetailedDSL.CAS
WHERE (((SubstanceAnalysis.CAS)=[Forms]![frmHSEChemicalInventory]![cmbCAS]));
```

The query is repeated in several locations within the application, as shown in Table [6-7], where the applicable values for the *SourceTable* are shown.

Search Example (5): Search Against an EC Number

A search string is enabled within the application to allow a user to enter an EC number (*cmbEC*) as a search string and then click on the search button to initiate the actual search. Once the search has been initiated, the SQL query statement, shown below, is run to return those records which precisely match the EC number.

```
SELECT MasterChemicalInventoryList.InvID, MasterChemicalInventoryList.SUBAID,
MasterChemicalInventoryList.TradeProductName, MasterChemicalInventoryList.Year,
MasterChemicalInventoryList.CountryofOrigin, MasterChemicalInventoryList.WhereFound,
MasterChemicalInventoryList.StorageLocation, MasterChemicalInventoryList.Manufacturer,
SubstanceAnalysis.SubstanceName, SubstanceAnalysis.CAS, SubstanceAnalysis.EC,
SubstanceAnalysis.QtyMixMin, SubstanceAnalysis.MinTon, SubstanceAnalysis.Max,
SubstanceAnalysis.QtyMixMax, SubstanceAnalysis.MaxTon, DetailedDSL.Description,
SubstanceAnalysis.SumMinTon, SubstanceAnalysis.SumMaxTon
FROM (MasterChemicalInventoryList INNER JOIN SubstanceAnalysis ON
MasterChemicalInventoryList.SUBAID = SubstanceAnalysis.SUBAID) INNER JOIN DetailedDSL ON
SubstanceAnalysis.SubstanceName = DetailedDSL.SubstanceName
```

The query is repeated in several locations within the application, as shown in Table [Appendix Table 13], where the applicable values for the *SourceTable* are shown.

Appendix Table 13: SQL Query Statements – Source Table Values

Search Query	**Application menu option**	**Form / query name**	**SourceTable Value(s)**
Search example 1: Select an RSL and return applicable records.	HSE: Master Chemical Substance Inventory List.	frmHSEChemicalInventory.	MasterChemicalInventoryList.
	HSE: Substance Analysis.	frmHSESubstanceAnalysis.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions *Component Drawing*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions (*PartNumber Drawing*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions (*Assembly Drawing*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions (*Component Specification*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions (*PartNumber Specification*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Article Definitions (*Assembly Specification*).	frmComplianceDefinitions.	SubstanceAnalysis.
	Regulatory Compliance: Supplier Declarations.	frmComplianceSupplierDecs.	SupplierDeclaration, DetailedDeclaration, SupplierList.
	Regulatory Compliance: Component 1 Ton Analysis (*Drawing*).	QRY_CompDrawSubstance.	SubstanceAnalysis.
	Regulatory Compliance: Component 1 Ton Analysis (*Specification*).	QRY_CompSpecSubstance.	SubstanceAnalysis.
	Regulatory Compliance: Component 1 Ton Analysis (*Supplier Declaration*).	QRY_CompSuppDeclaration.	DetailedDeclaration
	Regulatory Compliance: Part Number 1 Ton Analysis (*Drawing*).	QRY_PartDrawSubstance.	SubstanceAnalysis
	Regulatory Compliance: Part Number 1 Ton Analysis (*Specification*).	QRY_PartSpecSubstance.	SubstanceAnalysis.
	Regulatory Compliance: Part Number 1 Ton Analysis (*Supplier Declaration*).	QRY_PartSuppDeclaration.	DetailedDeclaration
	Regulatory Compliance: Assembly 1 Ton Analysis (*Drawing*).	QRY_AssyDrawSubstance.	SubstanceAnalysis.
	Regulatory Compliance: Assembly 1 Ton Analysis (*Specification*).	QRY_AssySpecSubstance.	SubstanceAnalysis.
	Regulatory Compliance: Assembly 1 Ton Analysis (*Supplier Declaration*).	QRY_AssySuppDeclaration.	DetailedDeclaration
Search example 2: Select trade / product name and return applicable records	HSE: Master Chemical Substance Inventory List (*Trade / Product name*).	QRY_ChemInventoryTradeName	SubstanceAnalysis.
	HSE: Substance Analysis (*Trade / Product name*).	frmHSESubstanceAnalysis.	SubstanceAnalysis.

Search Query	**Application menu option**	**Form / query name**	**SourceTable Value(s)**
	Materials: Substance Analysis	QRY_SubAnalTradeName.	SubstanceAnalysis.
Search example 3: Enter a substance name and return applicable records	HSE: Master Chemical Substance Inventory List (*Substance Name*).	QRY_ChemInventorySubstanceName.	SubstanceAnalysis.
	HSE: Safe Use Guidance (*Substance Name*).	QRY_SafeUseSubstanceName.	SafeUseGuidance.
	HSE: Substance Analysis (*Substance Name*).	QRY_SDSHSESubstanceName.	SubstanceAnalysis.
	Materials: Substance Analysis (*Substance Name*).	QRY_SubAnalySubName.	SubstanceAnalysis.
Search example 4: Enter a CAS number and return applicable records	HSE: Master Chemical Substance Inventory List (*CAS Number*).	QRY_ChemInventoryCAS.	SubstanceAnalysis.
	HSE: Safe Use Guidance (*CAS Number*).	QRY_SafeUseCASNumber.	SafeUseGuidance.
	HSE: Substance Analysis (*CAS Number*).	QRY_SDSHSECASNumber.	SubstanceAnalysis.
Search example 5: Enter a EC number and return applicable records	HSE: Master Chemical Substance Inventory List (*EC Number*).	QRY_ChemInventoryEC.	SubstanceAnalysis.
	HSE: Safe Use Guidance (*EC Number*).	QRY_SafeUseCASNumber.	SafeUseGuidance.
	HSE: Substance Analysis (*EC Number*).	QRY_SDSHSEECNumber.	SubstanceAnalysis.

Appendix 21: Detailed Author Adapted IEC6300 Risk Assessment methodology

The additional information used to generate the Supplier Risk Score as shown in Figure [6-24]. was recorded in a new SupplierRiskAssessment data load template. The author randomly assigned the risk criteria as shown in the following sub-sections, assessing, and scoring suppliers accordingly. The resultant risk assessment has been captured in the Dashboard application only. The criteria for the applicable assessments are shown as:

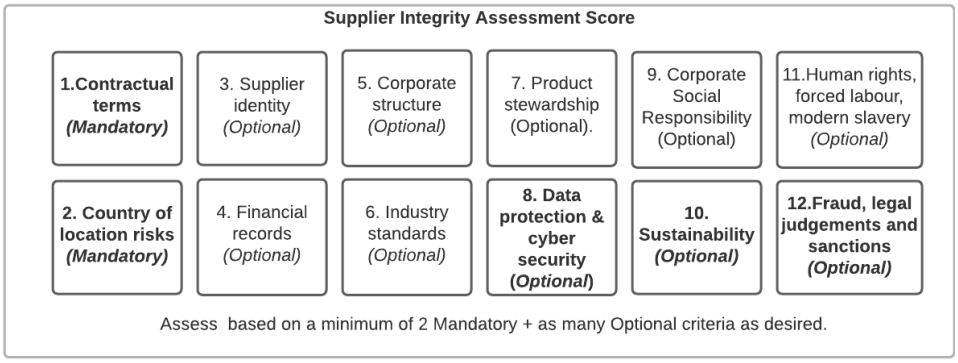
- Technical Design Authority criteria is shown in Appendix [10].
- AD Organisation Role criteria is shown in Appendix [11].
- Chemical Regulation Index criteria is shown in Appendix [12].
- Technical Document Index criteria is shown in Appendix [13].

Supplier Integrity Assessment (SIA)

The SIA analysis was generated to establish an index for the evaluation and trustworthiness of a supplier. The author has defined several criteria which may be utilised by an AD organisation to perform the SIA analysis. The criteria has been generated based on: (1) AD sector engagement as part of Delphi study and trade association engagements; (2) participation in trade association meetings assessing chemical regulations and environmental reporting requirements: (3) research papers (Takhar and Liyanage, 2018d; Takhar and Liyanage, 2020c; Takhar and Liyanage, 2020d), and; (4) the expected reporting outcomes from the EU Green Deal (EC, 2020c) and the EU Chemical Sustainability Strategy (EC, 2020f). It is anticipated that AD organisations will elect to utilise only the most applicable criteria and then benchmark suppliers consistently against the criteria to generate the SIA score for a given supplier.

Simulated SIA Analysis

Options 1, 2, 8, 10 and 12 were utilised as method to perform the initial SIA analysis undertaken within the simulation activities, as shown in Figure [Appendix Figure 26].



Appendix Figure 26: Criteria for SIA Analysis

Suppliers in scope were identified as (1) those suppliers of articles identified as having SVHCs under the EU REACH candidate list of substances as taken from supplier declarations where SVHC substances were declared from records contained within the SupplierDeclaration, DetailedDeclaration and PositiveDeclaration data load templates, and; (2) articles from suppliers as identified within the PurchasingForwardLoad data load template. Applicable data was extracted manually from relevant data load templates and inserted into the SupplierRiskAssessment data load template for further analysis. The Supplier Integrity Assessment Criteria is shown in Appendix [14].

Final SupplierRiskScore Calculation

The SupplierRiskScore is the final index score generated in the SupplierRiskAssessment data load template by performing the following calculation:

SupplierRiskScore = CRI score + TDI score + TDA score + ADOR score + SIA score

The higher the SupplierRiskScore value is the greater the potential risk for the article, the chemicals contained within it and the appraisal of the supplier. The SupplierRiskAssessment data load template contains the SupplierRiskScore scores generated. The Dashboard application displays the generated system output reports. Appendix [15] details the steps to generate the SupplierRiskScore.

Appendix 22: Detailed Framework Implementation Path

The detailed framework implementation tasks are shown in Table [Appendix Table 14]:

Appendix Table 14: Detailed Framework Implementation Tasks

#	Task	Comments

1.	Download and configure applicable research application (Database / Dashboard).	• Download, install and configure resultant research application(s):
		  ○ Appendix 8: Database application detailed installation and configuration instructions.
		  ○ Appendix 9: Dashboard application detailed installation and configuration instructions.
		  ○ Technical design documentation, detailed application design instructions.

2.	Review definitions and assumptions - Align to AD organisation as applicable.	• Review framework assumptions, making necessary adjustments for the given AD organisation:
		  ○ Definitions and assumptions.
		  ○ Adjust to given AD organisation.
		• Ensure stakeholders identified with expectations and tasks identified at a high level.

3.	Review supplier pre-engagement activities.	• Optional tasks in terms of examining supplier capabilities to report against any requested compliance reporting, with suggestions on the creation of clear contract terms:
		  ○ Supplier pre-engagement activities.
		  ▪ Contractual language.
		  ▪ Regulatory compliance readiness level.
		• Ensure suppliers understand reporting obligations, agree the formats for data exchange and required frequency of reporting.

4.	Agree supplier material declaration process - either via (i) standard data exchange standard or (ii) data load template formats.	

5.	Identify internal and external stakeholders.	• Review framework identified internal and external stakeholders, making necessary adjustments for given AD organisation:
		  ○ Detailed stakeholder analysis.
		  ▪ Adjust to given AD organisation.
		• Ensure all stakeholders, roles, processes, and tasks are covered in the context of chemical substance reporting.

6.	Agree internal business function acceptance of data load template population activities.	• Identify logical stakeholders who will be responsible for providing data and maintaining applicable data load templates. Based on outcomes of step 2 and step 5:
		  ○ Engage with identified stakeholders.
		  ○ Data load templates.
		  ▪ Framework data load templates identified against applicable business function(s).
		  ▪ List of chemical regulations and risk categorisation of regulatory substance lists.
		  ▪ Additional reference tables.
		  ▪ ***Noting*** that as business functions complete given data load templates, results in the required data on articles, article BOM structures, demand (sales orders), supply (purchase orders), etc to be populated and ingested into the resultant research application(s).

7.	Implement / update existing review boards.	• Identify existing / new control gates (review boards) where system output reporting is examined at business function level:
		  ○ Review boards.
		  ▪ Review board assessment logic.

#	Task	Comments
		▪ Establishing review boards. ▪ Suggested review boards.
8.	Business functions collect data from sub-systems.	• Collate required data from internal systems and external systems (supplier material declarations, regulatory substance lists): ○ Business functions collate data and update the applicable data load templates.
9.	Request and receipt material declarations from supply chain.	• Following existing procedures relating to requesting data from supply chain or any new processes implemented because of step 3, step 4, and step 5. ○ Review supply chain data collection activities. ○ Business functions collate data and update the applicable data load templates: ▪ PurchasingForwardLoad, ▪ SupplierList, ▪ SupplierGDPR, ▪ SupplierDeclaration, ▪ PositiveDeclaration.
10.	Populate Data Load Templates.	• Business functions collate data, structured and unstructured from multiple sources, importing the data into the applicable data load templates: ○ Transmit the populated data load templates to business function identified as being responsible for the management of the resultant research application(s).
11.	Import data load templates	• Understand how the resultant research applications function, from which, data load templates may then be ingested by the business function identified as being responsible for data maintenance of the resultant research application(s). ○ Review data model. ○ Review system analysis.
12.	Ingest data into applications (Dashboard / Database).	
13.	Business functions run reports and perform applicable data maintenance activities.	• Following step 11 and step 12, business functions may then run system output reports: ○ Review system output processing. ○ Available system output reports. ○ Identify data records and data load templates that require a given business function review, based on status field values. ○ Perform any resultant data maintenance activities related to data load templates. ○ Transmit the populated data load templates to business function identified as being responsible for the management of the resultant research application(s).
14.	Business functions perform data load template updates, setting status fields as applicable on applicable data load templates.	
15.	Function responsible for compliance reporting - run main risk identification system output reports.	• Business function responsible for compliance reporting perform identification of the impacts of chemical regulations. ○ Identification if applicable regulation notifications required. ○ Identify chemical substance and register uses with manufacturers. ○ Generate safe use guidance statements. ○ Perform customer declarations. ○ Update technical publications. ○ Perform any resultant data maintenance activities related to data load templates.
16.	Generate obligatory regulatory / customer notifications.	
17.	Generate data to feed into applicable review board(s).	

#	Task	Comments
18.	Review boards perform risk management activities.	• Following the identification and update / creation of review boards in step 7, the following tasks pertain to data to feed into applicable review boards, in addition to the reports identified in step 15 and step 16: ○ Review boards. ○ Suggested review boards and applicable data load templates. ○ Where the dashboard application is utilised, optional risks may be identified via the application of IEC 63000 methodology. ○ Perform review boards to perform formal risk management activities. ○ Where chemical substances have been identified for further control measures or are subject to public consultations, review potential external stakeholder engagement activities. ○ declarations. ○ Perform any resultant data maintenance activities related to data load templates.