# Application of the IUMSS Methodology for the Standardization and Integration of Management Systems in University Research Laboratories

by

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# Abstract

The purpose of this research is to investigate alternatives for the integration of management systems standards requirements into a single management system (MS) for university research laboratories and compare the resulting MSs after standardization and integration against the initial MSs.

There is a lack of research on the standardization and integration of quality management systems (QMSs), customer satisfaction management systems (CSMSs) and occupational health and safety management systems (OH&SMSs) in university research laboratories following the integrative use of management systems (IUMSS) methodology.

Interviews were conducted with four case studies laboratories (CSLs) staff and internal documentation was reviewed to learn about their MSs. The IUMSS methodology was applied to theoretically standardize and integrate the QMSs, CSMSs and OH&SMs of these CSLs. A comparison was conducted between initial MSs and resulting ones and between the steps followed for standardization and integration.

The methodology presented in the IUMSS Handbook (2018) can be used to standardize and integrate the QMSs, CSMSs and OH&SMs of university research laboratories. Since this study only involved the theoretical standardization and integration of these MSs, future research may study the challenges related to these systems' actual implementation and integration.

# Preface

This thesis is an original work by Renzo Jaramillo. The research project, of which this thesis is a part, was exempted from ethics approval from the University of Alberta Research Ethics Board, Project Name: “Application of safety, quality and customer satisfaction standards in university research laboratories”, No. Pro00083219, August 7, 2018.

**To the memory of my beloved father**
**Papito, gracias por todo**
**Siempre estarás en mi corazón**

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This thesis would not have been possible without the support of many people, and I want to take this opportunity to thank all of them:

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My beloved Belen, thank you for your patience, support and endurance through this long journey. You cannot imagine how much I love you!

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Thank you Stan, for giving me the opportunity to conduct research for the first time, for all your time, your patience, and guidance.

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# Glossary of Abbreviations and Terminology

| | |
|---|---|
| **FHP** | Feedback Handling Process |
| **CS** | Customer Satisfaction |
| **CSL** | Case Study Laboratory |
| **DIS** | Draft International Standard |
| **HIRADC** | Hazard Identification Risk Assessment Determining Control |
| **HLS** | High Level Structure |
| **IHS** | Information Handling Services |
| **IMS** | Integrated Management System |
| **ISO** | International Organization for Standardization |
| **IUMSS** | Integrative Use of Management System Standards |
| **MS** | Management System |
| **MSS** | Management System Standard |
| **OH&S** | Occupational Health and Safety |
| **OHSAS** | Occupational Health and Safety Assessment Series |
| **PAS** | Publicly Available Specification |
| **PDCA** | Plan, Do, Check, Act |
| **PPE** | Personal Protective Equipment |
| **QMS** | Quality Management System |
| **REB** | Research Ethics Board |
| **TR** | Technical Report |

# 1 Introduction

## 1.1 General

Every organization has a management system, whether its managers recognize it or not (ISO, 2018e). University research laboratories are not an exception. Previous research has explored the benefits of having an effective quality management system in research laboratories, including more transparency (Krapp, 2001; Biasini, 2012; Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020), more founding sources (Krapp, 2001; Grochau et al., 2010; Poli et al., 2015; Littrell et al., 2019), higher reliability and reproducibility of results (Krapp, 2001; Mathur-De Vré, 2000; Presot et al., 2014; Littrell et al., 2019), and increased confidence among stakeholders (Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020). An occupational health and safety management system is also critical for research laboratories as people working there are constantly exposed to new hazards introduced by changing technologies, materials and processes (Ramiza, 2017; Kulkami, 2019).

The ISO 9001 and ISO 45001 standards, which provide guidelines to plan and establish a quality management system and an occupational health and safety management system, respectively, could be used by university research laboratories to standardize their management systems. However, only one study examining the use of ISO 9001 in a university research laboratory was found in the literature (Walker, 2003). No research exploring the use of ISO 45001 in university research laboratories was identified through the literature review.

The performance of management systems based on standards such as ISO 9001 and ISO 45001 can be improved by using augmenting standards (e.g., ISO 10001 and ISO 10002) (Karapetrovic, 2005). These standards focus on a specific management system component (Karapetrovic, 2005), the customer satisfaction aspect in the case of ISO 10001 and ISO 10002. University research laboratories could benefit from implementing these augmenting standards to improve the performance of their management systems. However, no study covering the integration of an ISO 45001 occupational health and safety management system or an ISO 9001 quality management system with augmenting systems in the context of a university research laboratory was found in the literature.

This thesis covers a hypothetical standardization of the MSs of two university laboratories (CSL1 and CSL2) according to ISO 45001 and ISO 9001, respectively, and the integration of two

MSs in CSL3 (based on ISO 10001 and ISO 10002) and CSL4 (ISO 45001 and 10002), following the methodology presented in the latest version (i.e., 2018) of the IUMSS Handbook. This Handbook provides guidelines to effectively and efficiently incorporate the requirements of various ISO standards into an organization's MS (ISO, 2018e). Comparisons of different aspects of the CSLS' MSs and among the standardization and integration processes are also presented. These comparisons were possible since the case study laboratories have diverse characteristics, including various services and different geographic locations.

## 1.2 Organization of the thesis

Chapter 2 of this thesis presents a literature review on QMSs and OH&S MSs in research laboratories and integration of MSs, including the Integrated Use of Management System Standards (IUMSS) methodology, followed by the motivation for the research and the research objectives.

Chapter 3 explains the methodology used for this research project.

Chapter 4 presents a description of the current management systems of the four case study laboratories (CSLs) and the analysis of the management systems standards to be applied to these case studies (i.e., ISO 9001, ISO 45001, ISO 10001 and ISO 10002).

Chapter 5 illustrates the use of the IUMSS methodology for the implementation of the ISO 45001 and ISO 9001 requirements to the OH&S MS and QMS of CSL1 and CSL2, respectively.

Chapter 6 shows two examples of integration of MSs following the IUMSS methodology. The first example shows the integration of two augmenting standards (ISO 10001 and ISO 10002) in CSL3. The integration of MSs using an MSS (ISO 45001) and MSs based on an augmenting standard (ISO 10002) is illustrated in CSL4 in the second example.

Chapter 7 presents four types of comparisons among the management systems of the CSLs. In the first type of comparison, the initial MSs (i.e., before standardization or integration) are contrasted. The second comparison involves the MSs resulting from the standardization or integration process. In the third comparison, the initial and resulting MSs of each CSL are compared. The fourth comparison contrasts the standardization and the integration processes.

Chapter 8 shows the conclusions of the study, including the contributions and lessons learned. The limitations of the research and suggestions for future research are also detailed in this last chapter.

# 2 Literature Review

In this chapter, the literature review for topics related to this thesis is presented. Section 2.1 explains the methodology followed. Section 2.2 covers Management System Standards (MSSs) used in research laboratories. Section 2.3 addresses ISO 45001 and Occupational Health and Safety (OH&S) in research laboratories. Section 2.4 addresses the integration of MSSs requirements focusing on the Integrated Use of Management System Standards (IUMSS) methodology in research laboratories. Section 2.5 shows the motivation for the research. Finally, the research objectives are presented in Section 2.6.

## 2.1 Methodology

This section presents how the literature review was done during the time frame of fourteen months. A citation management software was used to collect, organize and cite the references and sources used in this thesis. Ten "search strategies" (University of Leeds, 2016, 00:05) were developed to ensure that the search process was systematic and replicable. The steps followed to create the search strategies were:

- Define a list of "key concepts" (University of Leeds, 2016, 00:25).
- Identify "keywords" (University of Leeds, 2016, 00:58) and synonyms.
- Combine keywords using Boolean operators to create a search string (University of Leeds, 2016).
- Identify databases to search (University of Leeds, 2016).

The first search strategy (S1) relates to overall management systems in laboratories. The subsequent search strategies related to:

- Function-specific MSs applied in any context: occupational health and safety MSs (S4) and customer satisfaction MSs (S10); and used in laboratories: occupational health and safety MSs (S3, S9), quality MSs (S2, S5), customer satisfaction MSs (S5, S6).
- Integration of management systems in general (S8) and in laboratories (S7).

Table 2.1 shows the ten search strategies used for the literature review.

## Table 2.1: "Search strategies" used for the literature review

| Search Strategies | Key concepts | Keywords and synonyms | Search string | Databases |
|---|---|---|---|---|
| **S1** | Management System<br>Laboratories | management system, standardized management system, systems<br>laboratory, laboratories, research laboratory, research laboratories | ("management system" OR "standardized management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | - ABI Inform<br>- Scopus<br>- Web of Science<br>- Compendex<br>- Emerald insight |
| **S2** | Quality Management System<br>Laboratories | Quality Management System, systems<br>laboratory, laboratories, research laboratory, research laboratories | ("quality management system" AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | |
| **S3** | Occupational health and safety management system<br>Laboratories | OHSAS 18001, ISO 45001<br>laboratory, laboratories, research laboratory, research laboratories | ("ohsas 18001" OR "ISO 45001" ) AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | |
| **S4** | Occupational health and safety management systems | OHSAS 18001, ISO 45001 | ("OHSAS 18001" OR "ISO 45001") | |
| **S5** | Quality and customer satisfaction standards<br>Laboratories | ISO 9001, ISO 10001, ISO 10002<br>laboratory, laboratories, research laboratory, research laboratories | ("ISO 9001" OR "ISO 10001" OR "ISO 10002") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | |
| **S6** | Customer satisfaction<br>Laboratories | Customer satisfaction<br>laboratory, laboratories, research laboratory, research laboratories | ("customer satisfaction") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | |
| **S7** | Management Systems<br>Integration Teaching organizations<br>Laboratories | management system, standardized management system, systems<br>Integration, Integrated research facility, research institute, teaching<br>laboratory, laboratories, research laboratory, research laboratories | ("management system*") AND ab("integrat*") AND ab("laborator*" OR "research facilit*" OR "research institut*" OR "teaching institut*") | |
| **S8** | Integrated use of management system standards | Integrated use of management system standards, IUMSS | ("IUMSS" OR "Integrated use of management system standards") | |
| **S9** | Occupational health and safety management system<br>Laboratories | occupational health and safety management system, occupational safety and health management system,<br>laboratory, laboratories, research laboratory, research laboratories | ("occupational health and safety management system" OR "occupational safety and health management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | |
| **S10** | Customer satisfaction standards | ISO 10001, ISO 10002 | ("ISO 10001" OR "ISO 10002") | |

Table 2.2 shows an example of a search strategy (S1) conducted in one database, specifically "ABI Inform." The screening process and the results of S1, considering five databases, are presented in Table 2.3. The full search tables showing the detailed search strategies and the traceability for each topic are included in Appendix A.

**Table 2.2: Example of a search strategy conducted in a database**

| **Search Strategy 1: Standardized management systems and laboratories** | |
|---|---|
| **Database: ABI Inform Complete:** Search carried out in ABI Inform Complete 2000 onwards.<br>**Date of search:** 07/24/2020 | |
| **Search** | **Results** |
| ab("management system" OR "standardized management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories")<br>Date: After 2000<br>Source type<br>Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals | 76 |

**Table 2.3: Example of a search screening summary**

| **Search Strategy 1: Standardized management systems and laboratories** | | | | | | |
|---|---|---|---|---|---|---|
| **Data Bases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | 76 | 69 | 74 | 28 | 19 | 266 |
| **Duplicates within same database** | 1 | 0 | 0 | 0 | 0 | 1 |
| **Total** | 75 | 69 | 74 | 28 | 19 | 265 |
| **Duplicates between databases** | 60 | | | | | 205 |
| **Not relevant (First round)** | 157 | | | | | 48 |
| **Not relevant (Second round)** | 25 | | | | | 23 |
| **Not relevant (Third round)** | 11 | | | | | 12 |
| **Final Results** | | | | | | **12** |

An extensive number of articles were obtained for the conceptual domains, so only articles from the last 20 years were considered for the search. Even with this time restriction, 1028 articles were found using the ten search strategies. Repeated articles among databases and searches were excluded. After two rounds of screening, the first one by article titles and the second one by abstracts, 204 unique articles were obtained. The third round of screening was conducted

reviewing the whole paper in terms of relevancy to the main focus of the thesis (i.e., research laboratories or institutions that use or have implemented MSSs, specifically ISO 9001, ISO 45001, ISO 10001 and ISO 10002, and the integration of MSs using the IUMSS methodology). As a result of this round, a total of 54 papers were included. In addition, 20 articles were identified as a result of a snowball process and added to the literature survey (see Appendix A for a detailed description of the snowball process). Therefore, 74 articles in total were included in this literature review. In addition, four MSc and Ph.D. theses relating to the topics were also consulted and included. Table 2.4 shows the screening process summary and final results.

**Table 2.4: Screening process summary and final results**

| Search Strategies | Results | Duplicates among databases | Sub-Total | 1st round: Not relevant (based on title) | Sub-Total | 2nd round: Not relevant (based on abstract) | Sub-Total | Duplicates with other searches | Sub-Total | 3rd round: Not relevant (based on whole paper) | Articles used |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 266 | 61 | 205 | 157 | 48 | 25 | 23 | 0 | 23 | 11 | 12 |
| S2 | 67 | 16 | 51 | 16 | 35 | 3 | 32 | 30 | 2 | 2 | 0 |
| S3 | 15 | 5 | 10 | 3 | 7 | 3 | 4 | 1 | 3 | 3 | 0 |
| S4 | 123 | 40 | 83 | 40 | 43 | 21 | 22 | 0 | 22 | 11 | 11 |
| S5 | 206 | 60 | 146 | 60 | 86 | 50 | 36 | 10 | 26 | 18 | 8 |
| S6 | 43 | 11 | 32 | 16 | 16 | 10 | 6 | 0 | 6 | 6 | 0 |
| S7 | 152 | 27 | 125 | 37 | 88 | 32 | 56 | 0 | 56 | 47 | 9 |
| S8 | 98 | 34 | 64 | 10 | 54 | 3 | 51 | 0 | 51 | 47 | 4 |
| S9 | 15 | 5 | 10 | 7 | 3 | 0 | 3 | 0 | 3 | 0 | 3 |
| S10 | 43 | 16 | 27 | 10 | 17 | 2 | 15 | 3 | 12 | 5 | 7 |
| **Sub-Totals** | 1028 | 275 | 753 | 356 | 397 | 149 | 248 | 44 | 204 | 150 | 54 |
| | | | | | | | | | | **Articles used** | 54 |
| | | | | | | | | | | **Snow ball articles used** | 20 |
| | | | | | | | | | | **Theses** | 4 |
| | | | | | | | | | | **Total of sources used** | **78** |

The MSSs cited were obtained from the Information Handling Services (IHS) Standards Expert database. The information collected from the sources described in Table 2.4 was used in the following sections:

- Section 2.2 covers Management System Standards (MSSs) used in research laboratories.
- Section 2.3 addresses ISO 45001 and Occupational Health and Safety (OH&S) in research laboratories.

- Section 2.4 addresses the integration of MSSs requirements focusing on the Integrated Use of Management System Standards (IUMSS) methodology.

  Table 2.5 shows the final number of articles used in each section.

**Table 2.5: Number of articles used in each literature survey section**

| Section number | Section Title | Search strategies | | | | | | | | | | Snowball |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | |
| 2.2.2.1 | Examples of QMS in research laboratories | 5 | | | | 6 | | | | | | 3 |
| 2.2.2.2 | Benefits of implementing QMSs in research laboratories | 4 | | | | 1 | | | | | | 4 |
| 2.2.2.3 | Challenges of implementing QMSs in research laboratories | 1 | | | | 1 | | | | | | 2 |
| 2.3.1 | Basics on ISO 45001 MSS | | | | 1 | | | 1 | | | | |
| 2.3.1.1 | Advantages of the ISO 45001 MSS | | | | 3 | | | | | | | |
| 2.3.1.2 | Benefits of the ISO 45001 implementation | | | | 3 | | | | | | | |
| 2.3.1.3 | Examples of ISO 45001 application | | | | 4 | | | | | 1 | | |
| 2.3.2 | Occupational Health and Safety (OHS) in research laboratories | 2 | | | | | | | | 2 | | 1 |
| 2.4.1 | Basics on integration | | | | | | | 1 | 1 | | | 5 |
| 2.4.2.1 | Integration Methodologies and the IUMSS handbook | | | | | | | 2 | 3 | | | 2 |
| 2.4.2.2 | Integrative Augmentation | | | | | | | 1 | | | 7 | 3 |
| 2.4.2.3 | Integration of management systems in higher education | | | | | | | 4 | | | | |
| **Number of articles** | | 12 | 0 | 0 | 11 | 8 | 0 | 9 | 4 | 3 | 7 | 20 |
| **Total number of articles** | | **74** | | | | | | | | | | |

## 2.2 MSSs used in research laboratories

Two main topics were covered in this part of the literature review section:

- Basics of MSSs in laboratories
- Application of QMSs in research laboratories

### 2.2.1 Basics of MSSs and laboratories

According to the International Organization for Standardization (ISO, 2019c), MSSs *"are designed to be applicable across all economic sectors, various types and sizes of organizations and diverse geographical, cultural and social conditions."*

Additionally, ISO (2019d) categorized MSSs in two types: Type A MSSs contain requirements against which an organization can claim conformance, whereas type B MSSs provide guidelines or supporting information (ISO, 2019d).

Although there are multiple examples of type A MSSs implementation in various industry sectors, this study focuses on their implementation in universities' engineering research laboratories. After a first literature search of such a topic, no results were found. For this reason, a wider search was conducted looking for examples of MSSs type A or type B implementations in research laboratories, specifically for QMSs (ISO 9001), OHSMSs (ISO 45001 or OHSAS 18001), CSMSs (ISO 10001) and CHMSs (ISO 10002).

In this thesis, examples of the implementation of type A MSSs (ISO 9001 and ISO 45001) are shown in Chapter five. Examples of the integration of type A and type B MSSs are shown in Chapter six (ISO 10001, ISO 10002, and ISO 45001).

### 2.2.2 Application of QMSs in research laboratories

#### 2.2.2.1 Examples of QMS in research laboratories

Some examples of implementation of QMSs were found in research laboratories related to biomedical (Davis et al., 2012; Ferdyn et al., 2019; Presot et al., 2014); biology (Lanati et al., 2019); virology (Audu et al., 2012); clinical (Garzon, 2015); microbiology (Simoes et al., 2016); and clinical physiology (Poli et al., 2015).

Other authors present examples of QMSs implemented in industry research laboratories. Including in food process quality laboratories (Biré et al., 2004), agronomic research laboratories (Molinéro-Demilly et al., 2018), in a public research centre that consist in sixteen laboratories that focus on industrial research services (Biasini, 2012), and in laboratories that offer EMC (Electro Magnetic Compatibility) test services (Kumar & Das, 2002).

Regarding university research laboratories, Vajda et al. (2006) show an example of implementing a component of a QMS for nuclear analytical techniques (Quality Control and Quality Assurance), resulting in an ISO 17025 accreditation.

Previous studies presented examples of implementation of quality systems based on the ISO/IEC 17025 standard in university laboratories (Rodima et al., 2005; De Nadai Fernandes et al., 2006; Vajda et al., 2006; Zapata-Garcia et al., 2007; Hullihen et al., 2009; Grochau et al., 2010). ISO/IEC 17025 provides general requirements for the competence of testing and calibration laboratories (ISO, 2017). Although in all these examples, the activities conducted by the university laboratories included teaching and research activities, as well as testing services for external

organizations, the scope of these quality systems only includes the services for external organizations (Rodima et al., 2005; De Nadai Fernandes et al., 2006; Vajda et al., 2006; Zapata-Garcia et al., 2007; Hullihen et al., 2009; Grochau et al., 2010). These services include performance tests for polymers and other materials (Hullihen et al., 2009; Grochau et al., 2010); radioactivity measurement (De Nadai Fernandes et al., 2006; Zapata-Garcia et al., 2007); chemical analyses (Rodima et al., 2005); and nuclear analyses, including alpha, beta and gamma-spectrometry and neutron activation analysis (Vajda et al., 2006).

Only one article describing the implementation of a QMS based ISO 9001 in a university laboratory was found in the literature (Walker, 2003). This implementation took place in an educational engineering laboratory, specifically in a software engineering applications laboratory at a university in South Africa (Walker, 2003).

Table 2.6 shows a summary of examples of standardized and non-standardized QMSs in different research laboratories.

**Table 2.6: Examples of certified and non-certified QMSs in research laboratories**

| Standardized QMS | | |
|---|---|---|
| **Authors** | **Laboratory type** | **QMS** |
| (Vajda et al; 2006) | Radiochemical Laboratory | ISO 17025 |
| (Davis, Emma et al., 2012) | Genetic epidemiology research laboratory | ISO 9001 |
| (Biasini, Valentina, 2012) | Public research centre focus on industrial research services | ISO 9001 & ISO 17025 |
| (Walker, 2003) | Software engineering applications laboratory (SEAL) | ISO 9001 & ISO 15504 |
| (Breustedt et al., 2011) | In vivo monitoring laboratory (IVM) | ISO 9001 & ISO 17025 |
| (Garzon, 2015) | Clinical laboratories in Latin America | ISO 9001, ISO 17025 & ISO 15189 |
| (Kumar & Das, 2002) | EMC test services laboratories | ISO 9001 |
| **Non-Standardized QMS** | | |
| (Bire et al., 2004) | Food and food process quality laboratories | |
| (Lanati, A. et al., 2019) | Molecular biodiversity laboratory | |
| (Molinéro-Demilly et al., 2018) | Agronomic research laboratories | |

#### 2.2.2.2 Benefits of implementing QMSs in research laboratories

Authors emphasized the importance of the traceability component of quality management systems to increase transparency in research projects (Krapp, 2001; Biasini, 2012; Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020) and, therefore, improve confidence among the stakeholders of research organizations (Krapp, 2001; Mathur-De Vré, 2000; Littrell et al., 2019;

Outaki et al., 2019; Estienne et al., 2020). Having a traceability system in place also reduces the likelihood of research fraud, including data manipulation (Cammann & Kleiböhmer, 1998; Outaki et al., 2019).

Implementing a quality management system in research laboratories increases the reliability of the results and ensures their reproducibility (Krapp, 2001; Mathur-De Vré, 2000; Presot et al., 2014; Littrell et al., 2019). The preservation and expansion of funding sources is another benefit associated with implementing quality management systems in the research context (Krapp, 2001; Grochau et al., 2010; Poli et al., 2015; Littrell et al., 2019).

Authors also identify an increase in research laboratory staff involvement, cooperation and openness and improved communication as benefits of the quality management system implementation (Biasini, 2012; Poli et al., 2015; Molinéro-Demilly et al., 2018; Littrell et al., 2019). Research laboratory staff is also more aware of the importance of their role and their contribution within the system (Poli et al., 2015).

Regarding university laboratories providing services to industry, authors recognize the satisfaction of client needs as one of the benefits of implementing a quality management system in these laboratories (Krapp, 2001; De Nadai Fernandes et al., 2006; Grochau et al., 2010). Another benefit of this implementation in university laboratories is that it provides an opportunity to teach graduate students quality-related topics in a realistic way and to increase their awareness about quality (Rodima et al., 2005; Zapata-Garcia et al., 2007; Hullihen et al., 2009).

#### 2.2.2.3 Challenges of implementing QMSs in research laboratories

Authors identified the high turnover rates of staff in research laboratories (e.g., Ph.D. students) as one of the challenges of implementing quality management systems in this context (Krapp, 2001; Littrell et al., 2019; Outaki et al., 2019). However, at the same time, this personnel's feature is precisely why documentation management is critical in these laboratories to avoid losing accumulated knowledge (Krapp, 2001; Molinéro-Demilly et al., 2018; Outaki et al., 2019).

Another challenge mentioned in the literature for implementing quality management systems in research laboratories is the wide variety of staff activities (Mathur-De Vré, 2000; Littrell et al., 2019) and the lack of roles definition (Mathur-De Vré, 2000). Initial researchers' resistance to the quality management system implementation due to their fear of loss of control

and freedom and a perceived negative impact on innovation is another challenge identified in the literature (Cammann & Kleiböhmer, 1998; Presot et al., 2014; Poli et al., 2015; Molinéro-Demilly et al., 2018; Littrell et al., 2019).

Some authors identify specific challenges for implementing quality management systems in university laboratories that provide services to industry (Rodima et al., 2005; De Nadai Fernandes et al., 2006; Zapata-Garcia et al., 2007). De Nadai Fernandes et al. (2006) point out that implementing quality management systems in the university context may not be perceived as a priority as staff's performance is usually assessed based on publications and teaching activities and not on the quality of the services provided to the industry. Another difficulty is that the laboratories are generally shared for service activities and teaching and research activities (Rodima et al., 2005; Zapata-Garcia et al., 2007).

#### 2.2.2.4 Suggestions for implementing QMSs in the research context

Authors point out the importance of considering the particular features of the research context when planning the implementation of a quality management system (Krapp, 2001; Poli et al., 2015). According to Poli et al. (2015), these features include the intangible nature of the "*finished products*" (e.g., publications, new technologies, technical reports and patents) and the diversity of customers, including employees, the industry that requests services, students, public agencies providing funding and the scientific community.

Krapp (2001) states that good quality documentation helps to reduce the negative impact of high turnover rates on the quality management of research laboratories. This author also recommends handling thesis work in university laboratories with a project management approach and constantly update research groups' leaders about research results to avoid losing this information due to the high turnover rates.

## 2.3 ISO 45001 and Occupational Health and Safety in research laboratories

Two main topics were covered in this literature review section:

- Basics of the ISO 45001 MSS, and
- Occupational Health and Safety (OH&S) in research laboratories.

### 2.3.1 Basics of ISO 45001 MSS

In March 2018, ISO published the ISO 45001 standard "*Occupational health and safety management systems – Requirements with guidance for use*" (ISO, 2018b). This standard replaced the OHSAS 18001 standard. It is expected that the publication of this new standard and its ISO recognition will accelerate the diffusion of certified occupational health and safety management systems (Glevitzky et al., 2019; Madsen et al., 2020).

In comparison to previous occupational health and safety management system (OH&SMS) standards, such as OHSAS 18001, this new standard puts a greater emphasis on leadership involvement and commitment (Boocock, 2017; Darabont et al., 2017; Zigulis, 2017; Darabont et al., 2018; Foulke, 2019; Neag et al., 2020; Nagyova et al., 2018). The responsibility for safety is not centralized on a specific person but across all leadership positions (Zigulis, 2017; Foulke, 2019). Another critical difference is the importance assigned to worker's participation (Darabont et al., 2016; Boocock, 2017; Darabont et al., 2017; Zigulis, 2017; Darabont et al., 2018; Foulke, 2019; Neag et al., 2020), including their involvement in the risk evaluation process (Darabont et al., 2016; Foulke, 2019). The importance of internal consultation is also emphasized in the ISO 45001 standard (Zigulis, 2017; Nagyova et al., 2018).

Unlike previous standards, ISO 45001 includes a requirement related to the "*context of the organization*" (Darabont et al., 2016; Boocock, 2017; Darabont et al., 2018; Nagyova et al., 2018). To fulfill this requirement, the organization needs to identify the internal and external issues that affect its ability to achieve its OH&S objectives (Darabont et al., 2016; Boocock, 2017; Darabont et al., 2018; Nagyova et al., 2018).

#### 2.3.1.1 Advantages of the ISO 45001 MSS

One of the main advantages of the ISO 45001 standard is that it is based on a continuous improvement approach (the PDCA cycle) like other ISO management system standards (e.g., ISO 9001, ISO 14001). This shared approach facilitates the integrative implementation of this certified OH&S MS in companies that have already implemented these management systems (Darabont et al., 2016; Foulke, 2019; Glevitzky et al., 2019; Neag et al., 2020). In addition, the ISO 45001 standard uses the ISO's high-level structure (Annex SL), which is common to all ISO management system standards. This common structure also facilitates the integrated implementation of an ISO

45001 OH&SMS with an ISO 9001 QMS and an ISO 14001 EMS (Boocock, 2017; Darabont et al., 2017; Darabont et al., 2018; Nagyova et al., 2018; Foulke, 2019).

#### 2.3.1.2 Benefits of the ISO 45001 implementation

The anticipated benefits of implementing an OH&SMS based on ISO 45001 include enhanced productivity (Boocock, 2017; Foulke, 2019); costs savings associated with early retirements, staff absenteeism and higher insurance premiums (Boocock, 2017; Foulke, 2019); improved reputation among stakeholders (Boocock, 2017; Foulke, 2019); maintenance and improvement of the company's position in the market, especially in international markets (Foulke, 2019; Neag et al., 2020).

#### 2.3.1.3 Examples of ISO 45001 application

Since ISO 45001 is a relatively new standard, only a few examples of its implementation have been found in the literature (Nagyova et al., 2018; Glevitzky et al., 2019; Beisseyev et al., 2020; Eridani et al., 2020; Zhao & Jiang, 2020). Three of these examples take place in manufacturing companies producing 3D printed implants (Nagyova et al., 2018) and food and beverages, including vegetable oils (Beisseyev et al., 2020) and bottled spring water (Glevitzky et al., 2019). The other implementation examples occur in the healthcare context during the COVID-19 pandemic (Zhao & Jiang, 2020) and higher education (Eridani et al., 2020).

In Nagyova et al. (2018), the manufacturing company already has an OH&S MS based on OHSAS 18001, but they want to transition to an ISO 45001 OH&S MS. The authors compare the current OH&S MS against the requirements of ISO/DIS 45001, identify gaps and propose actions to close these gaps.

In the two examples from the food and beverages industry (Glevitzky et al., 2019; Beisseyev et al., 2020), the authors mainly focus on identifying and assessing OH&S risks associated with their operations and proposing controls to reduce these risks. Therefore, these examples are primarily focused on some clauses of the ISO 45001 standard (e.g., clauses 6.1.2 and 8.1.2).

Although an article discussing the ISO 45001 standard in the higher education context, including university research laboratories, was found in the literature (Eridani et al., 2020), this

article focuses on the development of an application (using the Scrum model) to facilitate the implementation of this standard in an Engineering Faculty and not on the standard itself.

### 2.3.2 Occupational Health and Safety (OH&S) in research laboratories

People working in research laboratories are constantly exposed to new hazards due to the dynamic nature of their operations that involve everchanging processes, technologies, equipment and materials (Ramiza, 2017; Kulkami, 2019). In addition, in recent times, interdisciplinary research has become more complex and prevalent, posing new occupational health and safety challenges for research laboratories (Stuart & Sweet, 2013). Under this scenario, it is essential to assess the associated risks constantly, mainly when significant changes occur (Ramiza, 2017). A few examples were found in the literature about the Hazard Identification Risk Assessment Determining Control (HIRADC) analysis in the context of research laboratories. Athqiya et al. (2019) conducted this analysis in two nutrition laboratories in the Faculty of Public Health of the Universitas Airlangga in Indonesia, according to the requirements presented in OHSAS 18001, clause 4.3.1. Qurbasari et al. (2019) show the implementation of the hazard identification, risk assessment, and determinant control process in a university laboratory of audiovisuals aids, using the guidance of AS/NZS 4360:2004 – *Risk management*. Stuart & Sweet (2013) focus their study on a specific engineering control for university research laboratories: ventilation. They proposed a Laboratory Ventilation Management Program (LVMP) based on the integration of the guidelines provided by ANSI Z9.5 – *Laboratory Ventilation* and the continuous improvement approach presented in ANSI Z10 – *Occupational Health and Safety Management*.

Laboratories' workers, including investigators, students and professors, must understand the processes and the properties of the materials they are handling to avoid incidents (Kulkami, 2019). They must also identify when they need to consult subject matter experts (Ramiza, 2017). People that do not work in these laboratories may also enter these places. It is essential to have a clear policy and procedures about the presence of non-workers in these laboratories (Ramiza, 2017).

## 2.4 Integration and the use of IUMSS methodology in research laboratories

Two main topics were covered in this literature review section:

- Basics of integration, and
- The use of the IUMSS methodology in research laboratories.

### 2.4.1 Basics of integration

#### 2.4.1.1 Benefits of management systems integration

According to the IUMSS Handbook (2018e), an integrated management system is "*the outcome of the process of integrating requirements from multiple management system standards into a singular management system within an organization.*"

The benefits of implementing an integrated management system, instead of separate management systems, include:

- Higher efficiency (Salomone, 2008; Karapetrovic & Casadesus, 2009; Tari & Molina-Azorin, 2010; Zeng et al., 2011)
- A decrease in bureaucracy associated with paperwork (Salomone, 2008; Tari & Molina-Azorin, 2010; Zeng et al., 2011)
- Reduced costs (Asif et al., 2010; Zeng et al., 2011), including the costs of audits (Asif et al., 2010; Tari & Molina-Azorin, 2010)
- Optimization of audits (Salomone, 2008; Karapetrovic & Casadesus, 2009)
- Worker's improved understanding of their contribution to the organization's mission (Karapetrovic & Casadesus, 2009)
- Enhanced communication (Karapetrovic & Casadesus, 2009; Tari & Molina-Azorin, 2010; Asif et al., 2010)
- Optimization in training (Salomone, 2008; Tari & Molina-Azorin, 2010; Asif et al., 2010)
- Better-defined responsibilities (Salomone, 2008; Asif et al., 2010)
- Reduced conflicts between departmental goals and strategies (Salomone, 2008; Asif et al., 2010).

The benefits of integrating management systems include not only internal benefits but also external ones. Simon & Yaya (2012) found a strong relationship between the integrated use of management systems and its associated features (i.e., "*better use of systems*," "*system performance*," "*organizational strategic*," and "*internal cohesion*") with the satisfaction of customers.

### 2.4.2 IUMSS methodology in research laboratories.

#### 2.4.2.1 Integration Methodologies and the IUMSS handbook

Due to the benefits of the integration process, authors have explored various aspects of this process, including the "*integration strategy*," "*integration methodology*," "*integration level*," and "*audits systems' integration*" (Bernardo et al., 2015).

According to Karapetrovic (2003), there are three integration levels *"full integration*," when the components (objectives, resources and processes) of multiple MSs function as a single MS; "*partial integration,"* when just some MS' components are integrated but not all, and finally "no integration," when each MS is working separately.

The "*integration methodology*" refers to the models, tools and frameworks used in the integration process (Bernardo et al., 2015; Bernardo et al., 2018). Authors point out that this integration aspect is the "*least standardized*" (Bernardo et al., 2018) and that research on a specific methodology to integrate management systems is still scarce (Rebelo et al., 2014).

According to Bernardo et al. (2018), integration methodologies are based on:

a) Guidelines published by standardization bodies and,

b) Frameworks and models developed by various authors.

The guidelines issued by national standardization bodies include (Rebelo et al., 2014; Bernardo et al., 2017):

- Denmark – DS 8001:2005 (Dansk Standard, 2005) – "Integrated Management Systems",
- England – PAS 99:2012 (BIS, 2012) – "Specification of common management system requirements as a framework for integration",
- Spain – UNE 66177:2005 (AENOR, 2005) – "Management systems. Guide for the integration of management systems",

- Australian and New Zealand - AS/NSZ 4581:1999 (SAI Global, 1999) – “Management system integration— Guidance to business, government and community organizations.”

A recent review was performed in October 2021 to find new guidelines or standards that address the integration. Still, at the moment, no new guidelines issued by national standardization bodies were found. Also, it was learned that DS 8001:2005 and AS/NSZ 4581:1999 have been withdrawn, while PAS 99:2012 (BIS, 2012) and UNE 66177:2005 (AENOR, 2005) are current versions of such guidelines.

Despite the publication of these national standards, an international standard for integration has not been published yet (Sampaio et al., 2012; Bernardo et al., 2018). Although an international standard is lacking, in 2008, ISO published a handbook, "*The integrated use of management system standards*," (IUMSS), which provides a methodology, recommendations and examples to guide organizations throughout the integration process (ISO, 2008). A new version of this handbook was published in 2018 (ISO, 2018e).

Although some authors (Leopoulos et al., 2010; Simon et al., 2012; Rebelo, 2014; Bernardo et al., 2018) mention "*The integrated use of management system standards*" handbook when explaining integration methodologies, none of them show the application of the methodology provided in this handbook in a given context. To the best of my knowledge, the IUMSS was only exemplified in MSc theses like Borkovic (2009), Law (2010) and Astleitner (2018).

#### 2.4.2.2 Integrative Augmentation

According to Karapetrovic (2005), integrative augmentation refers to the enhancement of a component of an MS with processes modelled following the guidelines of an augmenting standard.

ISO 10001, ISO 10002 and ISO 10003 are examples of augmenting standards, focusing on the customer satisfaction management system component (Karapetrovic, 2008). These standards can be implemented separately to establish an independent management system or as subcomponents of an overall management system (Karapetrovic, 2008).

Previous studies have examined the augmentation of management systems (e.g., quality management system and information security management system) with management systems based on augmenting standards. For example, Hughes and Karapetrovic (2006) explored the

augmentation of a quality management system based on ISO 9001 with a complaint handling system based on the ISO 10002 standard in an electrical utility company. Borkovic (2009) shows the augmentation of a MS based on ISO 17025 with ISO/TR 10013. Vargas-Villarroel (2015) presents the augmentation of an information security management system based on ISO/IEC 27001 with subsystems based on ISO 10001, ISO 10002, ISO 10004 and ISO 10008 in a higher education environment. Ortiz and Karapetrovic (2020) presented a preliminary model for the augmentation of one of the components of an ISO 20000-1 service management system (i.e., "*business relationship management*") with a satisfaction code based on ISO 10001. In turn, this satisfaction code was augmented using the guidelines of ISO/IEC 27701. However, to the best of my knowledge, no previous study has explored the augmentation of an occupational health and safety management system based on ISO 45001 with a customer satisfaction management subsystem based on ISO 10002.

Previous related articles explored the integration of management systems based on ISO 10001 and ISO 10002 in different contexts. A code management system based on ISO 10001 was integrated with a complaint handling system based on ISO 10002 (Karapetrovic & Doucette, 2009; Karapetrovic, 2010) and a system based on ISO 10004 (Fernandez-Ruiz et al., 2017) to improve students' satisfaction in a higher education environment. Authors illustrated the integrated use of ISO 10001 and ISO 10002 (Khan & Karapetrovic, 2013, 2015) and ISO 10001 and ISO 10002 using a survey based on ISO 10004 (Khan et al., 2018) in the healthcare context. Dimkow & Ivanova (2012) provide an example of the combined use of the ISO 10001 and ISO 10002 standards in the telecommunications sector. However, to the best of my knowledge, no previous study has shown the integrative augmentation of systems based on ISO 10001 and ISO 10002 in a university research laboratory.

#### 2.4.2.3 Integration of management systems in higher education

Since the integration of management systems exemplified in this thesis has been carried out in four case study laboratories (CSLs) of two universities, a literature review was conducted to identify previous examples of integration of management systems in the higher education context.

Previous studies show the integration between quality management systems based on ISO 9001 and national quality guidelines for higher education published by the Romanian Agency for Quality Assurance in Higher Education (Moldovan, 2012) and the guidelines issued by BAN-PT, the National Accreditation Board of Higher Education in Indonesia (Legowo et al., 2020).

Other authors have explored the integration of management systems based on ISO assimilating standards and other management tools in the higher education environment. For example, Nurcahyo et al. (2019) show the integration of an environmental management system based on ISO 14001 and the UI Greenmetric performance measurement tool, while Pavel & Sarbu (2014) explored the integration of a quality management system based on ISO 9001 and Six Sigma tools in higher education institutions. However, no cases of integration were found in educational engineering research laboratories.

## 2.5 Motivation for research

The motivation for conducting this research comes from two perspectives, the academic and the practical. From the academic perspective, there are three reasons. First, there is a shortage of research on MSs integration in university research laboratories. Previous studies have examined the integration of MSs based on assimilating standards with augmenting standards in an electrical utility company (Hughes and Karapetrovic, 2006), testing and calibration laboratory (Borkovic, 2009), higher education (Vargas-Villarroel, 2015) and in the healthcare context (Ortiz & Karapetrovic, 2020). However, to the best of my knowledge, no previous study has explored the integration of a customer satisfaction MS based on ISO 10002 (full implementation) with an OH&S MS based on ISO 45001 (partial integration) in a university research laboratory. Previous articles explored the integration of management systems based on augmenting standards (e.g., ISO 10001 and ISO 10002) in higher education (Karapetrovic & Doucette, 2009; Karapetrovic, 2010), in the healthcare context (Khan & Karapetrovic, 2013, 2015; Khan et al., 2018), in the telecommunications sector (Dimkow & Ivanova, 2012). However, to the best of my knowledge, no previous study has shown the integrative augmentation of systems based on ISO 10001 and ISO 10002 in a university research laboratory.

The second academic reason is the lack of research on the use of the IUMSS methodology in university research laboratories. Although some theses illustrate the implementation of this

methodology (Borkovic, 2009; Law, 2010; Astleitner, 2018), only Borkovic's study (2009) took place in an industry testing and calibration laboratory.

The third academic reason is the publication of new versions of the IUMSS Handbook and the ISO 10001, ISO 10002 and ISO 45001 standards (i.e., the 2018 versions), whose use has not been extensively explored in the literature yet. The three theses mentioned previously illustrate the use of the earlier version (2008) of the IUMSS Handbook. Therefore, to the best of my knowledge, this thesis will be the first to explore an application of the new IUMSS handbook's version.

Regarding the latest versions of ISO 10001 and ISO 10002, since they are relatively recent (2018), there is a shortage of research on their use. Only Khan et al. (2018) and Ortiz and Karapetrovic (2020) explored their use in the healthcare context, but not in university research laboratories. In terms of the ISO 45001:2018 standard, only a few examples of its implementation were found in the literature (Nagyova et al., 2018; Glevitzky et al., 2019; Beisseyev et al., 2020; Eridani et al., 2020; Zhao & Jiang, 2020). Although Eridani et al. (2020) explore the application of ISO 45001 in higher education, this article focuses on developing a software application to support the implementation of the standard and not on the establishment of the management system.

From the practical perspective, two reasons motivate this research. Firstly, I had access to distinct types of CSLs (e.g., various research topics and countries) in which different paths for standardizing and integrating MSs could be exemplified. Secondly, there is a need to provide practical cases that illustrate the standardization and integration of management systems using the IUMSS methodology in university research laboratories.

## 2.6 Objectives of the research:

This research has the following six research objectives (ROs):

RO.1. Map the current CSLs' MSs to understand their objectives, activities, and resources.

RO.2. Select suitable MSSs to incorporate into the CSLs' MSs.

RO.3. Analyze the requirements of the selected MSSs.

These objectives are addressed in Chapters 3 and 4.

RO.4. Apply the IUMSS methodology theoretically to standardize two CSLs MSs according to the ISO 45001 and ISO 9001 standards. This objective is covered in Chapter 5.

RO.5. Apply the IUMSS methodology theoretically to integrate MSs based on assimilating and augmenting standards in two CSLs. This objective is tackled in Chapter 6.

RO.6. Compare the original MSs against the resulting MSs after standardization and integration and the steps followed for standardization against the steps followed for integration.

This objective is met in Chapter 7.

# 3 Methodology

## 3.1 Introduction

This chapter presents the methodology used for the research project. The first research goal of this study was to examine the applicability of four ISO standards in university research laboratories, specifically: ISO 9001:2015 (Quality Management Systems), ISO 45001:2018 (Occupational Health and Safety Management Systems) and two Customer Satisfaction Standards, ISO 10001:2018 (Guidelines for codes of conduct for organizations) and ISO 10002:2018 (Guidelines for complaints handling in organizations). A second research goal was to examine the possibilities for the integration of different management system standards requirements into a single management system for university research laboratories.

The steps described in the ISO Handbook: "*The Integrated Use of Management System Standards*" (IUMSS) (ISO, 2018e) were applied to examine the applicability of the mentioned standards and later integration of the chosen standards requirements. A case study research approach (Creswell & Poth, 2018) was followed. In this approach, the researcher examines real-life single or multiple "*bounded systems*" (Creswell & Poth, 2018). In this research, the "*bounded systems*" are the university research laboratories. Since the unit of analysis involves multiple cases in this research, this research is a "*multisite study"* (Creswell & Poth, 2018).

Data was gathered through interviews and from analysis of documentation to understand the processes held in four university research laboratories from different faculties and two different universities. This methodology is explained in more detail in Section 3.2.

In the first part of the project, three university research laboratories in a European country were visited as part of a three-month research stay. The second part was completed in one Canadian university research laboratory.

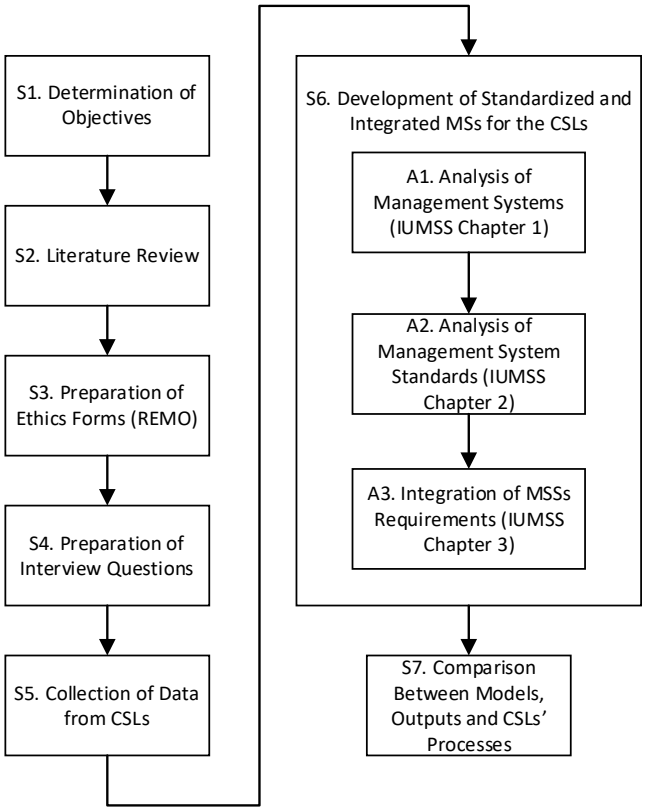
## 3.2 Research project methodology

This study is a qualitative case study, and, therefore, its data collection process involves various sources of information (Creswell & Poth, 2018). Information was gathered through interviews with people working in the laboratories and from documentation of public knowledge to understand the processes carried out in four different university research laboratories, "*case study laboratories*" (CSL). This general understanding of the processes allowed me to determine

the applicability of the ISO 9001, ISO 45001, ISO 10001 and ISO 10002 standards in university research laboratories.

The overall research project methodology is illustrated in Figure 3.1. It involves seven steps (from S1 to S7). The IUMSS component of the research is covered in sub-steps 6.1 to 6.3 in the research project methodology. The IUMSS methodology is discussed in section 2.3.

**Figure 3.1: Research Project Methodology**




In the first step (S1 Figure 3.1), the research objectives and questions were determined and are explained in detail in Chapter 2 (section 2.5). In step S2, a literature review was conducted. The results of this literature review are presented in Chapter 2 (sections 2.2 and 2.3). In S3, a research ethics application was completed and submitted to perform the research. In S4, a questionnaire was prepared for the interviews. In S5, data was gathered from the CSLs through interviews. In S6, the IUMSS methodology was used to develop standardized MSs and integrate MSSs into the CSLs' MSs. Finally, in S7, the results of the standardization and integration among CSLs were compared.

The updated versions of the ISO Handbook: "The Integrated Use of Management System Standards" (IUMSS) and the ISO 10001:2018, ISO 10002:2018 and ISO 45001:2018 standards were consulted as part of the literature review (S2 Figure 3.1). Also, previous research about the use of standards in university research laboratories was analyzed.

Research ethics permission was needed before starting the interviews. To that end, this permission was sought by preparing the ethics application forms through the university webpage (Step S3 Figure 3.1). However, after being revised by the Research Ethics Board (REB), the study was considered to be *"outside of the mandate of the REB and did not require or qualify for human ethics review"* (REB, 2018). Appendix B shows the application form and the letter received, respectively.

A questionnaire was developed to support the interviewing process (Step S4 Figure 3.1). The questions were designed to facilitate understanding the context and current management systems of the CSLs, including the objectives, resources, and processes carried out in these laboratories. The questionnaire also included questions related to the different ISO standards requirements to be applied. Appendix B shows the complete questionnaire. Table 3.1 shows some example questions from the questionnaire.

**Table 3.1: Questionnaire sample questions**

| **General questions to understand the context and the current MSs** |
|---|
| **ISO 9001**<br>• Which are the objectives and plans of the laboratories in terms of quality, safety and customer satisfaction? Are they communicated to all the people involved in the work? [clause 6]<br>• How do you monitor the fulfillment of the plans and objectives? [clause 7]<br>• What are the services that this laboratory provides? [clause 4] |
| **Questions regarding the requirements of a specific MSSs** |
| **ISO 45001**<br>• Do you have any documents (procedures, policies, etc.) related to safety? If so, which are they? How do you apply them? [Clause 6, 7] |
| **Questions regarding the requirements of a specific MSSs** |
| **ISO 10001**<br>• Are there any specific commitments that you are making to your customers? [clause 6] If so,<br>• How do you do that?<br>• What processes do you have to fulfill these commitments? [Clause 7]<br>**ISO 10002**<br>• What happens if there is a problem between the suppliers and/or clients and the laboratory? How do you collect the complaints? How do you handle the complaints? [Clause 7] |

Questions about the CSLs' activities and ISO standards requirements were developed to understand the MSs of each of the CSLs. These questions were asked to the laboratories' employees and the laboratories' directors (Step S5 Figure 3.1). Notes were taken during the interview to record the responses. In addition, follow-up questions were formulated during the interview when necessary to clarify and fully understand the processes and activities. All the interviews were semi-structured, a combination of closed and open-ended questions accompanied by follow-up "why" and "how" questions (Adams, 2015) and were conducted face to face in the laboratories. In some cases, the interviewees showed how an activity was performed using an example (e.g., experimental sample, test or prototype).

The information gathered through the interviews was complemented with information collected from a CSL's documentation of public knowledge, such as pamphlets and brochures.

Once data from the CSLs were gathered, it was analyzed using the IUMSS methodology (Step S6 Figure 3.1). Sections 3.6, "*Maintain and improve integration*" and 3.7, "*Apply lessons learned in the organization*" of the IUMSS methodology, are addressed in the conclusions of this research (Chapter Eight) because the actual implementation of the standards has not taken place. Additional information about integration methodologies, including the IUMSS methodology, are discussed in section 2.4.2.1.

The first step in using the IUMSS methodology involved examining the current MSs and representing them using flowcharts (Sub-step 6.1 in figure 3.1). Secondly, the MSSs (ISO 9001, ISO 45001, ISO 10001 and ISO 10002) suggested for application in the CSLs were analyzed (Sub-step 6.2 in figure 3.1). These two sub-steps will be illustrated further in chapter Four.

Thirdly, a model for standardizing the MSs of the first two CSLs was proposed. Two or more different MSSs requirements were incorporated into an integrated management system (IMS) for the last two CSLs (Sub-step 6.3 Figure 3.1). The models, which include examples and suggestions, could be presented to the directors of the CSLs so they could consider them for implementation. The proposed models could be used to apply one single ISO MSS or to integrate multiple ISO MSSs' requirements into one single MS. The models are illustrated further in chapters Five and Six.

Finally, different CSLs were compared to find commonalities and differences among them and identify difficulties in implementing the suggested models (Step S7 in Figure 3.1). These comparisons are illustrated in Chapter Seven.

## 3.3 Management Systems (MSs)

A management system is *"…a set of interrelated or interacting elements of an organization to establish policies and objectives and processes to achieve those objectives"* (ISO, 2015; ISO, 2018e). As part of the implementation of the methodology presented in the IUMSS handbook (ISO, 2018e), the current MSs of the CSLs were documented and analyzed. The "guiding questions" suggested in each section of Chapter One of the IUMSS methodology were used to examine the MSs.

The first step was to understand the CSLs' context, risk and opportunities. The guiding questions presented in section 1.2 of IUMSS (2018) were used to that end.

The second step was to identify the elements of the current CSLs' MSs and understand the interrelationships between them. The essential elements of the MSs that are illustrated further in Chapter Four include:

- *"Objectives"* (related to section 1.3.1 of IUMSS, 2018)
- *"Processes"* (related to section 1.3.2 and 1.3.4 of IUMSS, 2018)
- *"Organizational structure and resources"* (related to section 1.3.3 of IUMSS, 2018)
- *"Services and customers"* (section 1.1.2 of IUMSS, 2008)
- *"Stakeholders"* (section 1.1.3 of IUMSS, 2008)
- *"Performance feedback"* (section 1.3.4 of IUMSS, 2018)

Understanding the interrelationships among the elements of the MSs (related to 1.4 of IUMSS 2018) means understanding how these elements work together to achieve goals and objectives in a systemic way to satisfy customers and stakeholders (ISO, 2018e). Flowcharts are used to represent these interrelationships in Chapter Four.

## 3.4 Management System Standards (MSSs)

Similarly to the analysis of the MSs explained in the previous section, to analyze the MSSs, the "guiding questions" presented in each section of Chapter Two of the IUMSS methodology were answered.

Currently, the CSLs MSs do not have any MSSs implemented. However, as explained in section 2.2.2.2, having a standardized MS in research laboratories offered many benefits, which could be an excellent motivation for the CSLs to adopt an MSS.

The selection of an MSS for each CSL was based on the laboratory's objectives and the standard's capacity to support those objectives. Further analysis of the MSSs chosen to be applied in the CSLs will be discussed in section 4.2 of Chapter Four.

Chapter Three of the IUMSS methodology was followed in Chapters Five and Six of this thesis. Chapter Five presents the standardization process in CSL1 and CSL2, using ISO 45001 (Occupational health and safety management systems requirements) and ISO 9001 (Quality management systems requirements). Chapter Six shows the integration of multiple ISO standards requirements. For CSL3, the standards examined were ISO 10001 (Guidelines for code of conduct for organizations) and ISO 10002 (Guidelines for complaints handling in organizations). For CSL4, the standards analyzed were ISO 45001 (Occupational health and safety management systems requirements) and ISO 10002 (Guidelines for complaints handling in organizations).

During the standardization and integration, two different approaches for mapping the MSSs requirements were used. These approaches ("*matrix*" and juxtaposition) are explained in Chapter Three of the IUMSS handbook. The commonalities and differences among both approaches are further discussed in Chapter Seven.

## 3.5 Summary

In this chapter, the methodology used in this study was presented. Sub-chapter 3.2 presented the overall Research Project Methodology. Sub-chapter 3.3 described how the CSLs MSs were analyzed. Sub-chapter 3.4 outlined the MSSs used for further standardization and integration into the CSLs MSs.

# 4 Description of the current MS in the CSLs

This section shows the results of applying Chapters one and two of the IUMSS methodology. The analysis of the current management systems (MSs) of the CSLs is presented in sub-section 4.1. The management systems standards (MSSs) that could be applied to the CSLs are examined in sub-section 4.2.

## 4.1 CSLs MSs

The first part of the research was conducted in three research laboratories, which belong to a university located in a European country. One of the laboratories is located in the capital city, and the other two are located in a province. These laboratories (CSL1, CSL2 and CSL3) are dedicated to academic research and have an educational component of the curricula in diverse courses. The laboratories receive funds for research from the European Union and the university budget for their daily operation. Most of the laboratories' machines were acquired with funding from the European Union. Because of the funding agreement regulations, these machines must be used for research only for a certain number of years. After that period, they can be used for commercial uses in agreement with local companies. In the case of materials, once the laboratory director approves a specific project, the researcher asks for the materials required to run an experiment or a project.

The second part of the research was completed in a Canadian university research laboratory (CSL4). The laboratory is dedicated to industry research and has funding from private institutions. It runs its daily operations with the university budget.

Among the main stakeholders of the CSLs are the directors of the laboratories, the dean of the laboratory's faculty, the teaching and technical community, grant agencies, the academic community, students and society.

Regarding the performance feedback, all the CSLs have a similar way of managing it. They have periodic and annual meetings to review the performance of the laboratories and the fulfilment of their objectives. However, none of the CSLs had performance metrics related to research. Regarding the client's feedback, none of the CSLs have a system to manage the feedback they receive from internal and external clients, though all the CSLs directors recognize the value of this feedback.

The main elements of MSs described in section 3.3 were identified for the current CSLs MSs and are presented next. Flowcharts representing the interactions among these elements are also shown.

For each CSL, services and objectives are illustrated first. The organizational structure is then explained. Next, internal and external clients are presented. Finally, the CSL's processes are shown in flowcharts.

### 4.1.1 Case Study Laboratory 1 (CSL1)

This laboratory focused on ion beam technology, plasma deposition and modification, and ion beam analysis. It specializes in material implantation and measurement of material surfaces. It is an advanced technology laboratory that focuses on thin layers and materials modification. It also traces elements of materials. It uses high radiation and energy. Currently, the laboratory is devoted mainly to research, but the laboratory director wants to provide more services to the local industries as a long-term goal in the future.

Six people work in the laboratory and are only researchers. The internal clients are mainly Ph.D. students and post-doctoral fellows who use the facilities for research and development. People from other laboratories on campus that ask for an expert opinion on ion beam topics are also internal clients.

External clients are private industries and other universities that are interested in ion beam technology. For instance, if a company requires a material analysis in the laboratory, the company provides samples of this material. After testing the samples for analysis of the material, the researchers can perform experiments on it. The following flowchart, Figure 4.1, describes the processes performed in the laboratory.

**Figure 4.1: CSL1 Current MS Flowchart**

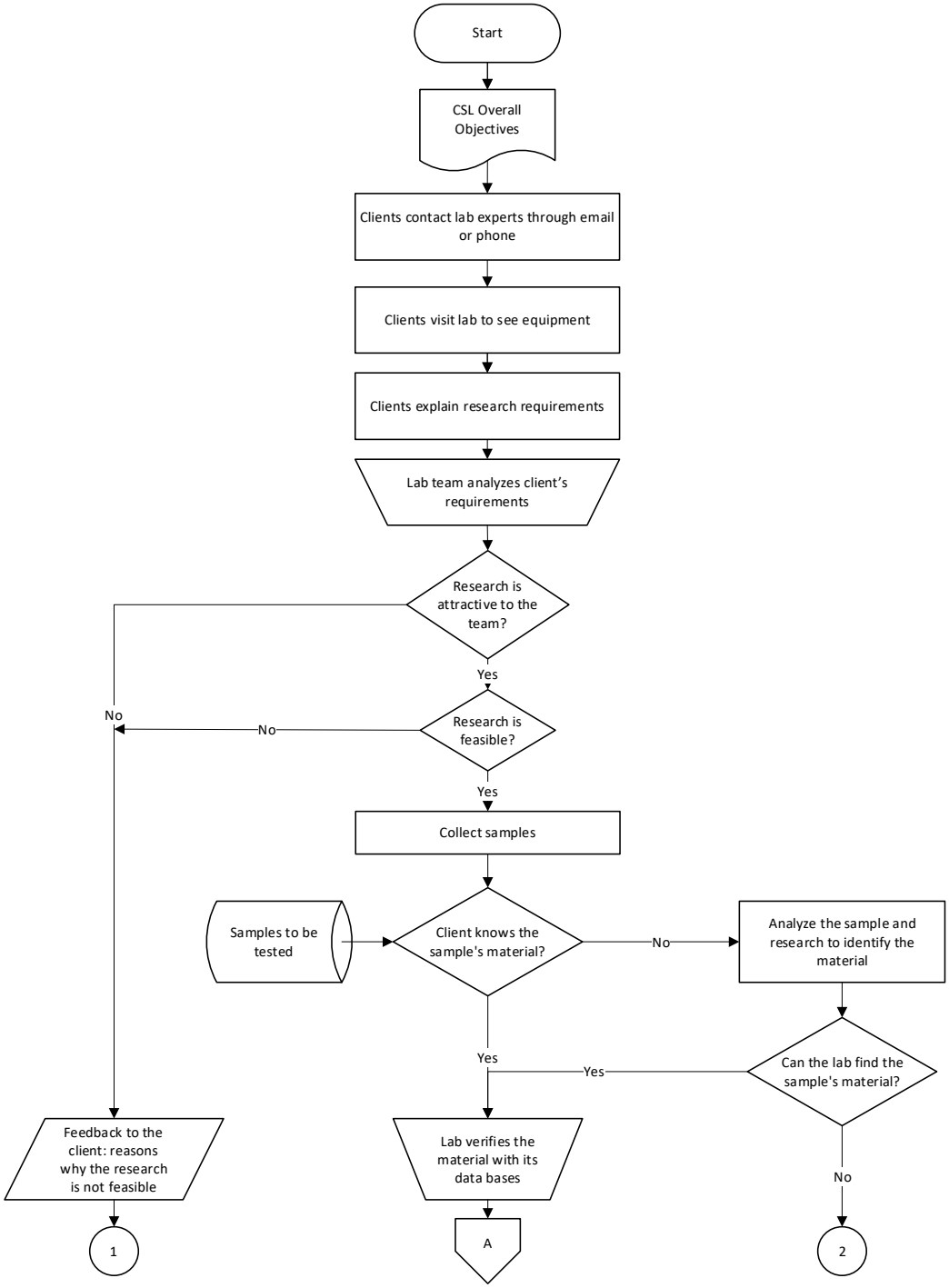
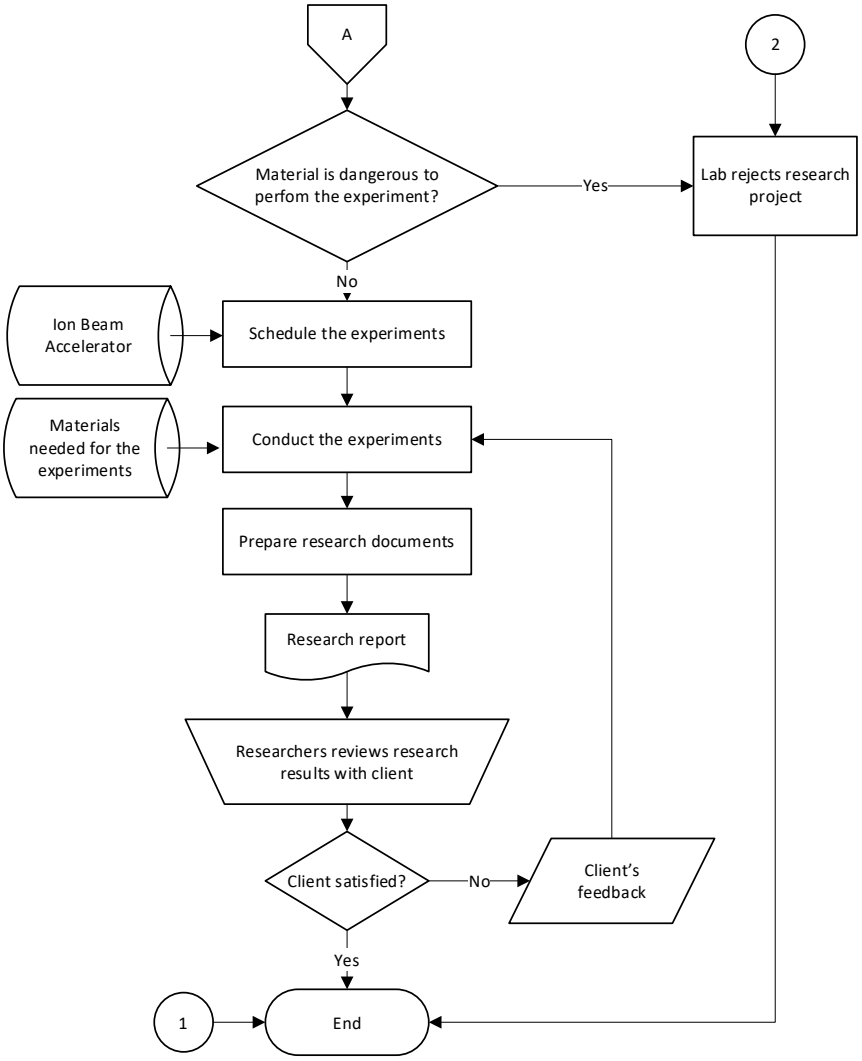


**Figure 4.1 (continued): CSL1 Current MS Flowchart**




### 4.1.2 Case Study Laboratory 2 (CSL2)

This laboratory focuses on research and development in the field of production and control of parts with complex shapes by 5-axis machining and 3D contact and non-contact measurement. The CSL has different machines and equipment that focus on four aspects:

- Machining of pieces and tools
- Welding
- Measuring systems
- Modelling (3D printing and scanning)

One coordinator manages each group of machines. This person oversees the daily operation and maintenance of the machines. The coordinator is also in charge of the research conducted in their area of expertise and applying for grants. Around 15 people work in this laboratory, including professors, graduate students and researchers.

Most of the prototypes developed in this laboratory are based on reverse engineering of specific parts that clients want to replicate. The laboratory's main internal clients are undergraduate students who receive the practical component of a particular course or for the development of a bachelor's thesis. The second group of internal clients are MSc and Ph.D. students who use the laboratory to conduct research and develop their research theses. Finally, people from other laboratories on campus that collaborate in research and consulting are also internal laboratory clients.

Among the external clients are different industries like automotive, aerospace, nuclear plants and bicycle manufacturers. These industries provide a sample of pieces that require laboratory services. Based on these samples, the researchers can reverse engineer them.

Regarding the resources, once the laboratory director approves a specific project, the researcher asks for the resources required to run the experiment or project.

**Figure 4.2: CSL2 Current MS Flowchart**

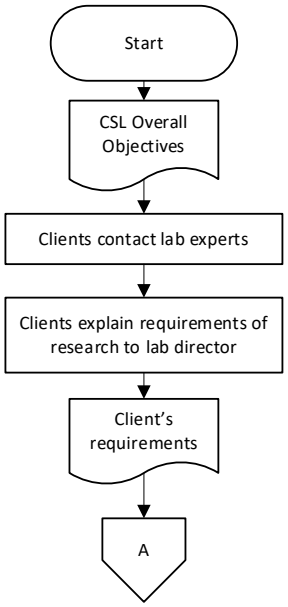
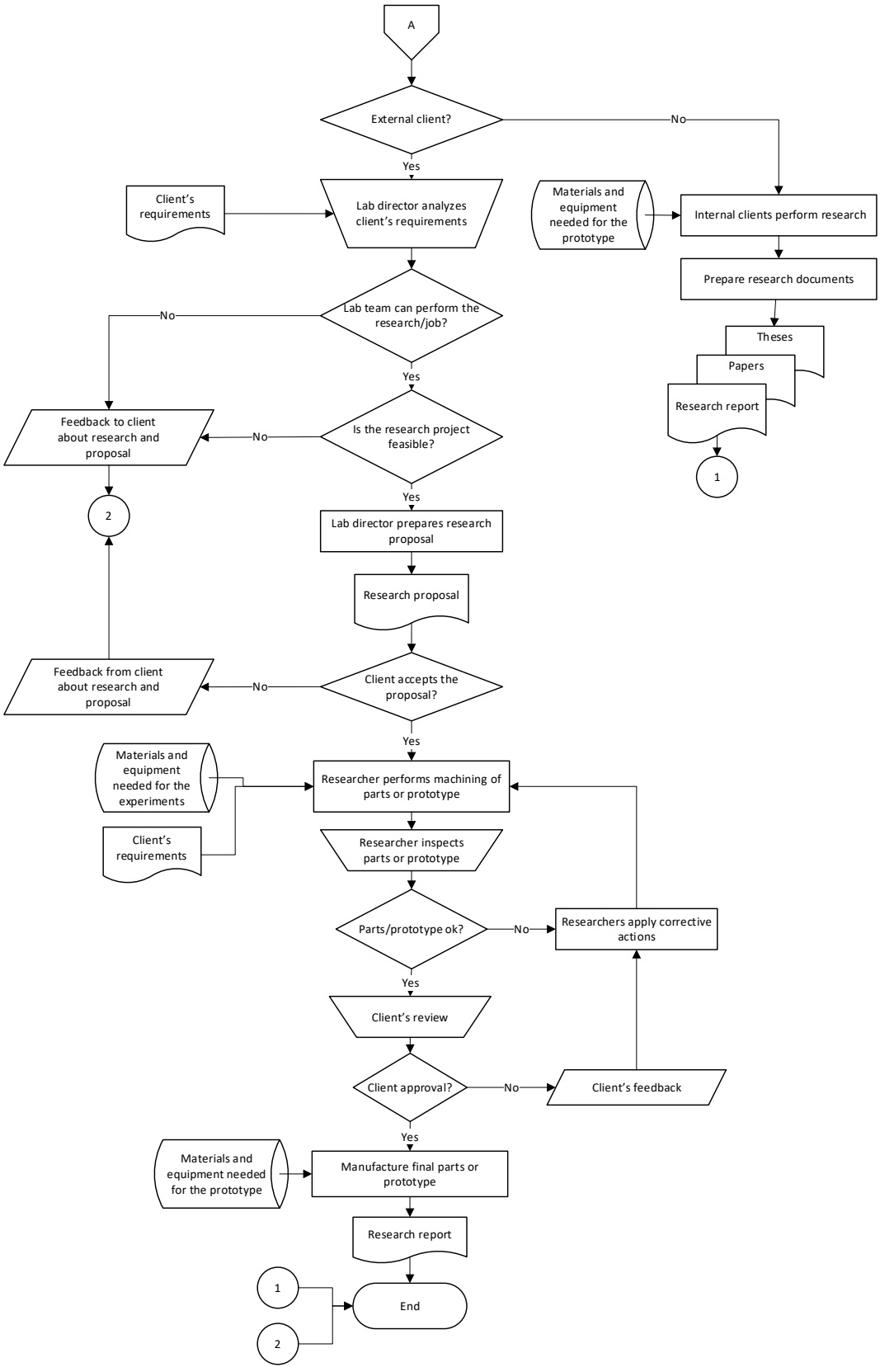


**Figure 4.2 (continued): CSL2 Current MS Flowchart**



### 4.1.3 Case Study Laboratory 3 (CSL3)

This CSL belongs to the Mechanical Engineering department of a university located in Europe. This laboratory specializes in two main research topics:

- Particles and powder materials.
- Heat and mass transfer.

Expected outputs of the research in CSL3 include a prototype of specific equipment, new methods for compacting particles and powder materials, and research papers about these topics. Other services apart from the research include drawings, strength calculations, and the manufacture of basic equipment.

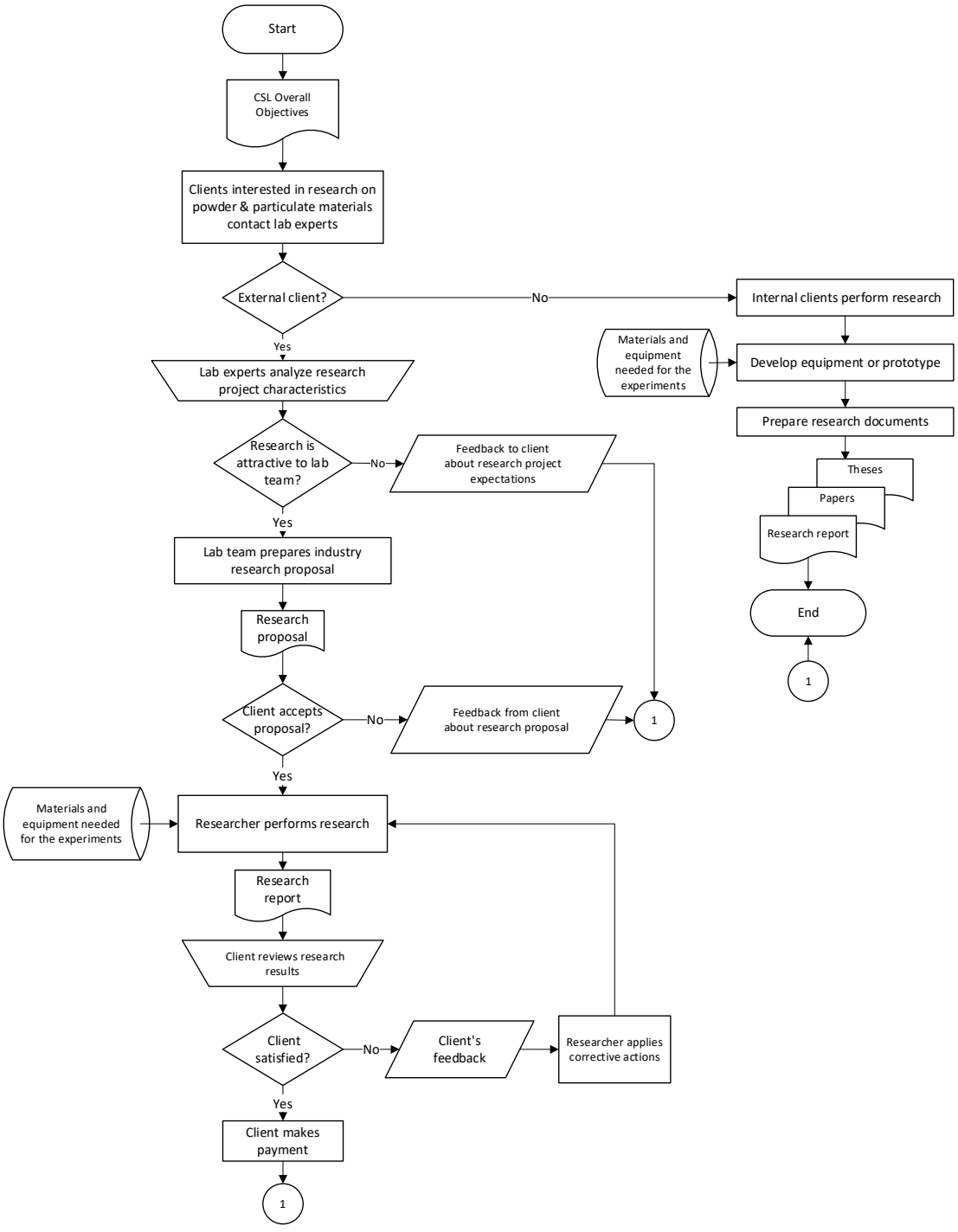
One of CSL3's main objectives is to obtain more government or private institution funding to renovate equipment. Another objective is to attract more masters' students to conduct research on powder materials and heat mass transfer.

Six persons work in this laboratory, four in materials and two in heat and mass transfer. The staff consists of professors, assistant professors, graduate students and researchers. Internal clients include undergraduate students who use the services of CSL3 as part of their courses or for the development of their theses. Secondly, graduate students also use the facilities for conducting research. The third kind of internal clients are people from other laboratories on campus that usually ask for expert opinions and conduct experiments on specific topics and collaborative research.

Among the external clients are different industries, such as chemical, pharmaceutical, fertilizers and textiles.

Figure 4-3 shows the flowchart that identifies the main processes performed in the CSL3. The flowchart shows the relationships among the processes and the needed resources to deliver the CSL3 services.

**Figure 4.3: CSL3 MS Current Flowchart**



### 4.1.4 Case Study Laboratory 4 (CSL4)

This CSL is in a Canadian university. The laboratory focuses on materials science and researches materials for military and aerospace industry purposes.

The laboratory director carefully chooses the topics to work on, focusing primarily on big problem-solving research topics of long-term duration (from four to six years). The director usually rejects short-term collaboration projects, except in some cases where he knows that the project will result in publishing papers for students. The research is very independent as the university has a flat organization and the laboratory director has the freedom to decide which research to conduct.

Currently, the laboratory receives funding from the defence ministry of a North American country government to perform the research. The resources are provided from grants and the university to acquire materials for the experiments and run the laboratory. There is a significant amount of materials preparation involved for research purposes.

The CSL's internal clients are mainly students from undergraduates to Ph.D. and post-doctoral fellows. Most undergraduate students are part of co-operative programs whit local companies who want to apply academic research in the laboratory. The laboratory director receives oral feedback from the internal clients and tries to improve their satisfaction based on this feedback.

The external clients are the collaborators or organizations that provide funding for the research. They include North American countries' defence ministries, industries, sponsors and provincial government. The laboratory director sends monthly and yearly reports for external clients, and they give feedback on the research progress.

The laboratory students follow the experiments' safety procedures, such as always working in pairs and using personal protective equipment (PPE). There is also orientation training for new laboratory students. These occupational health and safety controls are specified in the CSL manual.

In terms of quality, they attempt to follow testing standards for performing experiments, for instance, the American Society for Testing and Materials (ASTM) for mechanical testing. Still, generally, they have flexibility in applying it. They maintain research quality by actively publishing, attending conferences regularly and using the feedback from collaborators.

**Figure 4.4: CSL4 Current MS Flowchart**

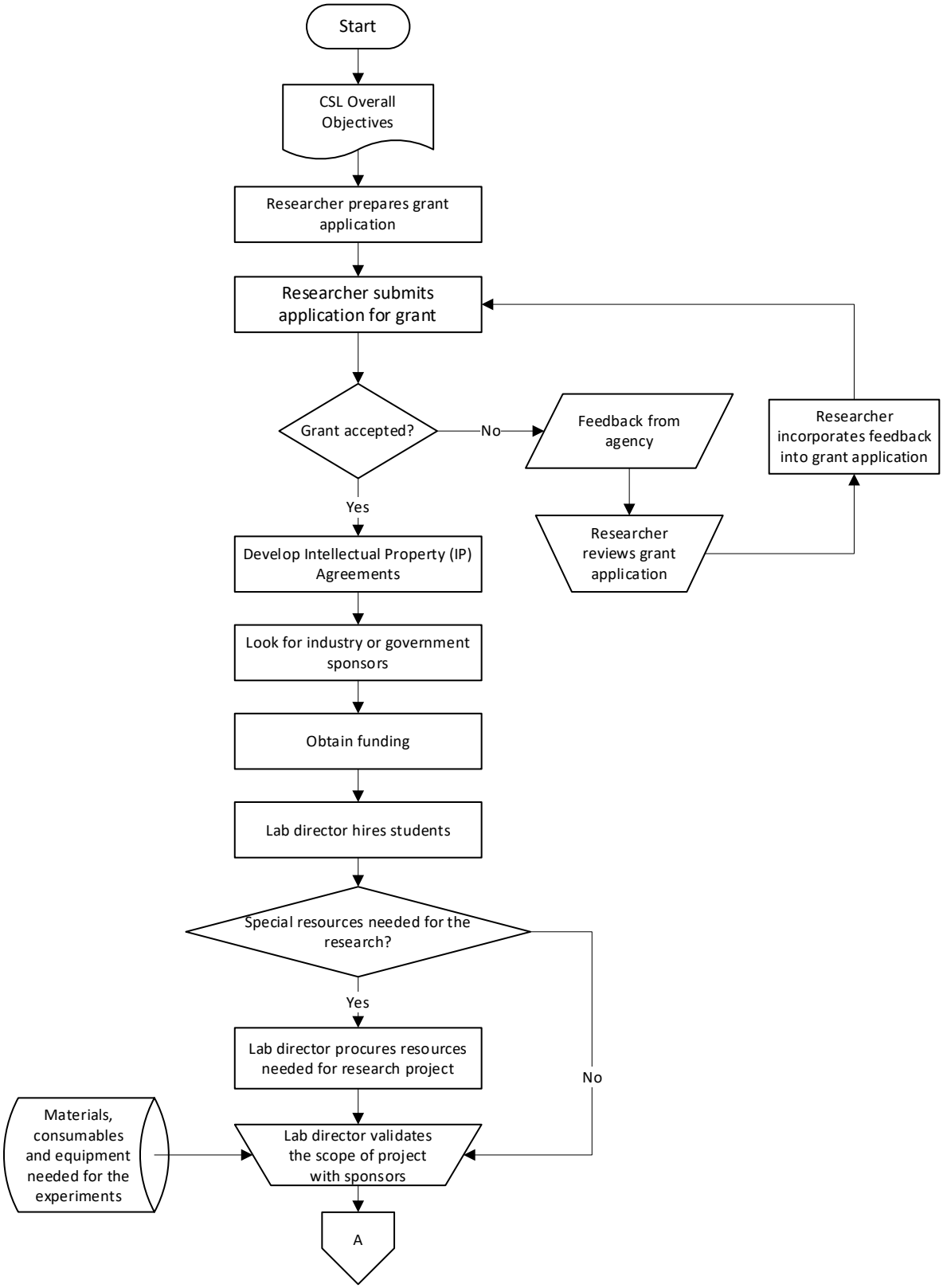
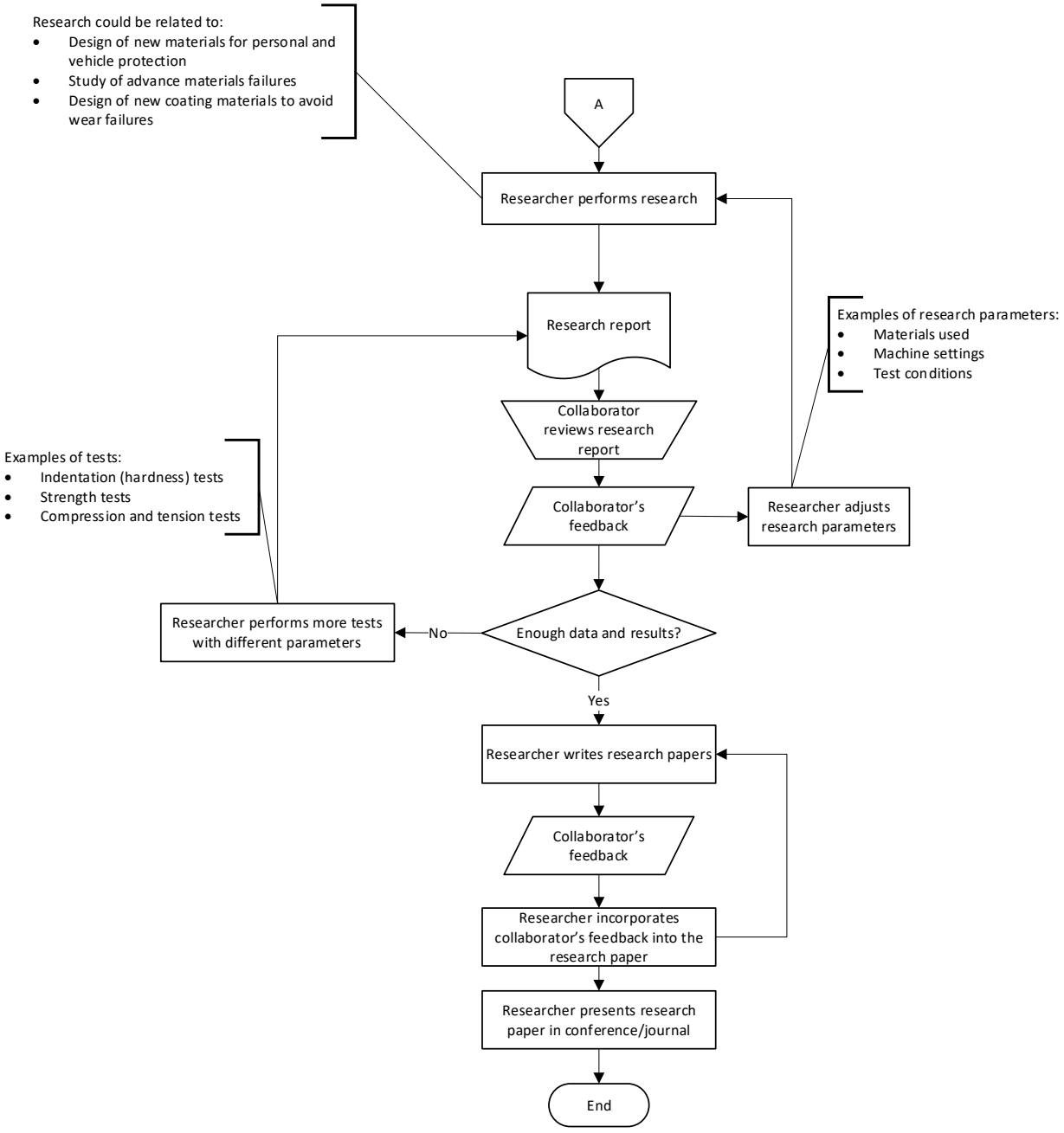


**Figure 4.4 (continued): CSL4 Current MS Flowchart**




## 4.2 Analysis of Management System Standards (MSSs)

After exploring the CSLs' MSs using interviews and public knowledge documentation, it was determined that the CSLs did not have standardized MSs that could help them address their goals and objectives. The CSLs can look for suitable MSSs to that end based on each situation.

There are several standards that laboratories can choose to follow to improve their operations. The election of a particular standard over others should be based on the specific objectives and priorities of MSs. For example, suppose quality is a top priority, laboratories could apply the generic standard for the whole QMS, ISO 9001 -- *Quality Management Systems*. Laboratories could also use a standard to enhance an element of their QMS, such as ISO 10012 -- *Measurement management systems -- Requirements for measurement processes and measuring equipment*. Another option could be for the laboratory to use a sector-specific standard, such as ISO/IEC 17025:2017 for *Testing and Calibration Laboratories* or ISO 15189:2012, which includes requirements for *Quality and Competence for Medical Laboratories*.

If a laboratory seeks to formalize its occupational health and safety management system, it could implement a management system based on ISO 45001 – *Occupational Health & Safety Management Systems*. ISO also publishes occupational health and safety standards applicable to particular laboratory types, such as ISO 15190:2020, that provides *Requirements for Safety for Medical Laboratories*. However, this standard is not relevant for the CSLs. The American National Standards Institute (ANSI) also publishes occupational health and safety standards. ANSI/ASSP Z10.0 – 2019 defines requirements for an occupational health & safety management system. Other occupational health & safety standards published by ANSI for laboratories include a standard for *Laboratory Ventilation* (ANSI/AIHA Z9.5-2012) and a standard for *Emergency Eyewash and Shower Equipment* (ANSI/ISEA Z358.1-2014).

ISO MS standards were selected for implementation and further integration. One of the reasons for choosing ISO MSSs for the CSLs is because they have a common "High-Level Structure" (HLS). According to (ISO, 2018e) "*This commonality may make it easier for the organization to read and understand the MSSs. It may also make it easier for the users during analysis and implementation of MSS's requirements to identify their commonalities and differences".*

ISO MSSs were also applied since, as the largest developer of standards globally (ISO, 2019c), ISO has gained a reputation and provides the confidence and a level of credibility that interested parties are looking for. *"ISO's management system standards (MSS) are among some of the most widely used and recognized documents that we publish"* (ISO, 2019c).

According to the ISO's website (ISO, 2019c), ISO has published 22878 standards, of which more than 80 are MSSs. From these ISO standards that CSLs could implement, two overall MSSs (ISO 9001, ISO 45001) and two augmentative standards (ISO 10001 and ISO 10002) were chosen.

ISO 45001 and ISO 9001 are used to illustrate the standardization process in the first two CSLs. The reasons for showing the standardization process in these specific CSLs are academic and practical. From the theoretical perspective, it is interesting to explore the applicability of MSSs in university research laboratories since there is limited literature about their relevance in this context. As part of the literature review, only one study (Walker, 2003) examining the implementation of an ISO 9001 QMS in a university laboratory specialized in software engineering applications was found.

From a practical standpoint, these CSLs are primarily focused on industry research related to the automotive and nuclear energy sectors. These industries have strong quality and occupational health and safety regulations and are important to the CSLs because they provide funding and research topics. In addition, these industries are one of the main destinations of employment for graduate students in Research and Development (R&D). The implementation of an ISO 9001 QMS in university laboratories will be beneficial for these graduate students as they can learn quality-related themes in a real context and increase their understanding of the importance of quality (Rodima et al., 2005; Zapata-Garcia et al., 2007; Hullihen et al., 2009).

The reason to show the integration process in the last two CSLs is because of their characteristics, that is to say, both CSLs have less complex MSs. For instance, both are small laboratories with simple processes, with few people involved in the research activities. It is easier to integrate multiple MSSs into simple MSs like these.

Two approaches are used to illustrate the integration process for the last two CSLs. The first approach demonstrates the integration of two augmentative standards, ISO 10001 and ISO 10002, into the MS of CSL3. From a theoretical point of view, it is interesting to examine how the integration process works with two augmentative standards in a university research laboratory since there is a lack of research about this topic. Previous studies have explored the integration of ISO 10001 and ISO 10002 in the healthcare context (Khan & Karapetrovic, 2013, 2015), the telecommunications sector (Ivanova, 2012) and an undergraduate engineering course

(Karapetrovic & Doucette, 2009; Karapetrovic, 2010). However, no study exploring the combined use of these standards in a university laboratory has been found in the literature.

The second approach illustrates the integration of one assimilative standard (ISO 45001) and one augmentative standard (ISO 10002) in CSL4. From a theoretical perspective, it is interesting to explore the integration process involving an assimilative and an augmentative standard. Previous research shows the augmentation of an ISO 9001 QMS with an ISO 10002 complaints handling system (Hughes and Karapetrovic, 2006) and the enlargement of an information security management system based on ISO/IEC 27001 with subsystems based on ISO 10001, ISO 10002, ISO 10004 and ISO 10008 in a higher education environment (Vargas-Villarroel, 2015), and the augmentation of an ISO/IEC 20000-1 service management system with an ISO 10001 customer satisfaction code system (Ortiz & Karapetrovic, 2020). However, no study has shown the augmentation of an ISO 45001 occupational health and safety system with an ISO 10002 complaints handling system.

The differences and commonalities between these two approaches will be discussed further in Chapter Seven. Next, an analysis of each of the four MSSs to be used for standardization and integration in the CSLs will be presented.

### 4.2.1 CSL1: ISO 45001

The unique characteristics of this CSL in terms of safety, such as the use of high radiation energy and hazardous materials, make it a suitable case for the implementation of ISO 45001. Occupational health and safety are one of the top concerns for the laboratory's top management. The new ISO 45001 standard will help the laboratory team address the different hazards and risks that arise from the laboratory operation. Its implementation can also increase the laboratory's productivity (Boocock, 2017; Foulke, 2019), decrease costs associated with staff's absenteeism and higher insurance premiums (Boocock, 2017; Foulke, 2019) and enhance the reputation of the laboratory among its stakeholders (Boocock, 2017; Foulke, 2019).

Another reason for choosing this particular MSS is that it follows the ISO's high-level structure (Annex SL), common to all ISO MSSs. This common structure can help integrate the OH&S MS with other ISO MSs (Boocock, 2017; Darabont et al., 2017; Darabont et al., 2018;

Nagyova et al., 2018; Foulke, 2019). Therefore, it makes sense that the CSL implement ISO 45001 in case they decide on future integration with other MSs that follow ISO MSSs.

Moreover, ISO 45001 MSS is relatively new, as it became public in March 2018, and there is little research about it. According to ISO, this MSS takes into account *"other International Standards in the area such as OHSAS 18001, the International Labour Organization's ILO-OSH Guidelines, various national standards and the ILO's international labour standards and conventions."* (ISO, 2019a). Therefore, it would be interesting to implement this new MSS to CSL1 for reference for future researchers and practitioners.

### 4.2.2 CSL2: ISO 9001

Since the primary research focus of this laboratory is to develop prototypes of specific parts that clients from the industry want to replicate, test or find new materials to increase durability, the laboratory needs to provide confidence to their clients. Implementing a QMS in a research laboratory improves confidence among their stakeholders (Krapp, 2001; Mathur-De Vré, 2000; Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020). It increases transparency in research projects (Krapp, 2001; Biasini, 2012; Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020), improves the reliability of the results and guarantees their reproducibility (Krapp, 2001; Mathur-De Vré, 2000; Presot et al., 2014; Littrell et al., 2019). Therefore, applying the requirements of ISO 9001 to some critical laboratory processes will enhance customer satisfaction and provide quality assurance of the products and services provided.

Another reason for implementing ISO 9001 in this CSL is because of the reputation the CSL can obtain from it. According to ISO, ISO 9001 *"can be used by any organization, large or small, regardless of its field of activity. In fact, there are over one million companies and organizations in over 170 countries certified to ISO 9001"* (ISO, 2019b). Therefore, by incorporating ISO 9001 into the CSL2 MS, the laboratory will demonstrate its ability to consistently produce and test parts with complex shapes according to industry clients' requirements. Also, if the laboratory decides to integrate more MSSs requirements into the system later, it would be easier to do because of the HLS that ISO 9001 has.

### 4.2.3 CSL3: ISO 10001 and ISO 10002

As this laboratory is mainly focused on research and development for the industry, and there is a need to increase the satisfaction of external clients, the standards that would be applicable to implement would be customer satisfaction standards.

There are five customer satisfaction standards to choose from: ISO 10001, ISO 10002, ISO 10003, ISO 10004 and ISO 10008. The implementation of ISO 10001 and ISO 10002 is suggested in this thesis. ISO 10001 would help develop certain quality guarantees for the external clients, which is a novelty for research laboratories. ISO 10002 would help establish a system to handle the external client's feedback adequately. Implementation of both MSSs should increase clients' satisfaction.

ISO 10008 was not selected because this standard covers business-to-consumer (B2C) electronic transactions, which is not related to the CSL aim. The ISO 10003 standard will not be used either because it is for use in external dispute resolution. In the case of CSL3, the feedback and complaints are solved very quickly and do not escalate to a dispute. Also, the CSL3 would need first to establish a feedback handling system to escalate after.

Regarding ISO 10004, this standard helps define and develop processes to monitor and measure customer satisfaction in organizations. This standard could be better used in the second phase of implementation after a basic customer satisfaction system is implemented in CSL3. ISO 10001 and 10002 could help establish this basic customer satisfaction system.

Therefore, implementing ISO 10001 and ISO 10002 MSSs will provide the necessary framework in the current management system that would help the laboratory enhance customer satisfaction.

### 4.2.4 CSL4: ISO 45001 and ISO 10002

As the primary research focus of this CSL is doing high-impact tests on materials for defence purposes, there could be risks of getting injured while conducting experiments, and occupational health and safety are fundamental matters to CSL4. Therefore, implementing an international MSS such as ISO 45001 that holistically covers safety would benefit CSL4.

Regarding ISO 10002, applying this standard would help the CSL manage the feedback they receive from internal and external clients. This sub-system would be necessary because,

during the interviews, the director stated that they do not handle this feedback properly. He also pointed out that some helpful feedback gets lost, and opportunities for improvement are missed. Therefore, establishing a standardized MS to handle the feedback can benefit the CSL.

As discussed in Chapter Two, ISO 45001 is relatively new, considering it became public in March 2018. The third edition of ISO 10002 was published in July 2018. While it is true that it is not a new standard, this new edition considers alignment with the last version of ISO 9001, which has a similar structure with ISO 45001, which would help the integration of both requirements into the CSL MS.

Augmentative standards do not have the same structure as assimilative standards. Therefore, from a research perspective, it is interesting to study the integration between an assimilative standard, such as ISO 45001, and an augmentative standard, for example, ISO 10002. As discussed in previous sections, no previous study has examined the integration of management systems based on these two standards in any context. Previous research has not studied the individual implementation of MSs based on these standards in a university laboratory either.

## 4.3 Summary

This chapter presented the application of Chapters one and two of the IUMSS methodology into the CSLs. In sub-chapter 4.1, the CSLs were introduced, and their current management systems (MSs) were analyzed. To that end, flowcharts that represent the current MSs were drawn based on data collected from the CSLs. Sub-chapter 4.2 presented the analysis of the management systems standards (MSSs) that will be further applied to the CSLs.

# 5 IUMSS Methodology: Standardization

## 5.1 Introduction

This chapter will examine the applicability of specific MSSs in two CSL's MSs by applying the IUMSS methodology to establish a standardized management system. The CSLs chosen for the standardization are CSL1 and CSL2. The MSSs examined are ISO 45001 and ISO 9001 implemented in CSL1 and CLS2, respectively.

As part of the implementation of the IUMSS methodology, the steps and the guiding questions suggested in Chapter Three are followed.

## 5.2 Lead, determine the scope and plan the implementation [IUMSS, 3.1-3.3]

This part of the thesis will cover the first three steps of Chapter Three of the IUMSS methodology: sections 3.1, 3.2 and 3.3.

The CSLs directors are responsible for providing the leadership and direction necessary for the implementation of the MSSs. The reasons to standardize or integrate specific MSSs within the CSLs MSs were analyzed in section 4.2 of the thesis.

The scope for standardization is to apply ISO 45001 in the CSL1 and ISO 9001 into the CSL2. An equal number of clauses will be implemented for both CSLs to illustrate how to implement the clauses of different standards. Five clauses will be implemented. According to the HSL, three of them will be common to all MSSs and two will be specific for each MSS. The chosen clauses and an explanation for each clause are shown in section 5.3.2 of this thesis.

## 5.3 Connect MSSs requirements with the laboratories MSs [IUMSS, 3.4]

In this section, points 3.4.1 (*"Structure MS"*), 3.4.2 (*"Structure MSS requirements"*), and 3.4.3 (*"Map MSSs requirements against the management system*") of the IUMSS methodology are covered for each of the laboratories.

### 5.3.1 Structure MS

Flowcharts of the current MSs of the laboratories were shown in Chapter 4. These flowcharts illustrate the interrelationships and interdependencies among processes and help understand each laboratory's MS.

### 5.3.2 Structure MSS requirements

The next step in the implementation process is the analysis of the MSS requirements. To illustrate this analysis in the first two CSLs (ISO 45001 and ISO 9001, respectively), I have selected provisions from different elements of the standards (Table 5.1), in this case, operation and performance evaluation, to show a representative example.

The common requirements for both MSSs are from clause nine: 9.1, 9.2 and 9.3. These common sub-clauses were selected because the existence of a performance evaluation process was not identified through the interviews with CSLs' directors. This is shown in flowcharts in Figures 4-1 and 4-2.

The specific requirements for ISO 45001 are from clause eight: 8.1 and 8.2. These sub-clauses were selected because CSL1 has some occupational health and safety controls, policies and procedures in place, but there is no active control process to ensure those controls are working correctly. If we analyze the MS flowchart (see Figure 4-1), it can be observed that the CSL1 does not have a formal process dedicated to verifying that those controls are effective. In addition, although CSL1 has a procedure for responding to emergencies, this clause can provide more structure to this procedure. The implementation of clauses 8.1. and 8.2 is critical since an emergency situation in a nuclear facility like CSL1 could be catastrophic.

For the case of ISO 9001, the specific requirements are 8.2 and 8.3. These sub-clauses were chosen because both would help CSL2 enhance the design and manufacture of pieces from their clients, which is the primary focus of CSL2. As can be noticed in the CSL2 flowchart (figure 4-2), no processes are allocated to address the design and manufacture.

Table 5.1 summarizes the requirements applied to each CSL.

**Table 5.1: MSS Requirements to be implemented in each CSL for Standardization**

| CSL1 - ISO 45001 | CSL2 - ISO 9001 |
|---|---|
| 8.1 Operational planning and control<br>8.2 Emergency preparedness and control<br><br>9.1 Monitoring, measurement, analysis and performance evaluation<br>9.2 Internal audit<br>9.3 Management review | 8.2 Requirements for products and services<br>8.3 Design and development<br><br>9.1 Monitoring, measurement, analysis and evaluation<br>9.2 Internal audit<br>9.3 Management review |

### 5.3.3 Mapping MSS requirements against the CSLs' MSs

The tabular or "*matrix*" approach (ISO, 2018e) was used for the mapping process. This approach uses a table with the MSS requirements selected to be implemented and analyzes their relationship with the current MS elements (i.e., goals, processes and/or objectives). The mapping process allowed for identifying the need for adding elements to the current MSs to fulfill the MSS requirements.

Tables 5.2 and 5.3 show the mapping for CSL1 and CSL2, respectively. The tables show in the columns the MSSs requirements and in the rows the MS elements. The relationship between each MSS requirement and each MS element is shown by inserting an "x" in the crossing field.

The "*matrix*" approach (ISO, 2018e) was selected due to the characteristics of the CSLs. Both CSLs are research centers with ample facilities, various machines and many researchers, and therefore, they have complex processes. Due to these processes, the relationships between the MSS requirements and the CSL MS can be better shown in a tabular way than using a juxtaposition approach.

**Table 5.2: Mapping ISO 45001 requirements against CSL1 MS**

| | ISO 45001: 2018 Sample Clauses | | | | |
|---|---|---|---|---|---|
| **CSL1 MS Elements**<br>**Processes** | **8.1 Operational planning and control** | **8.2 Emergency preparedness and control** | **9.1 Monitoring, measurement, analysis and performance evaluation** | **9.2 Internal audit** | **9.3 Management review** |
| Clients contact laboratory experts through email of phone | | | | | x |
| Clients visit laboratory to see equipment | x | | x | | |
| Clients explain research requirements | x | | x | | x |
| Laboratory team analyze client's requirements | x | | x | | x |

## Table 5.2 (continued): Mapping ISO 45001 requirements against CSL1 MS

| CSL1 MS Elements | ISO 45001: 2018 Sample Clauses | | | | |
|---|---|---|---|---|---|
| **Processes** | **8.1 Operational planning and control** | **8.2 Emergency preparedness and control** | **9.1 Monitoring, measurement, analysis and performance evaluation** | **9.2 Internal audit** | **9.3 Management review** |
| Researcher collects samples | x | | x | x | |
| Researcher analyzes sample and research to identify the material | x | x | x | x | |
| Researcher confirms that material is safe to work on | | x | x | x | x |
| Laboratory rejects research project if the material is not safe | x | x | x | x | x |
| Researcher schedules the experiments | | x | x | | x |
| Researcher conducts the experiments | x | x | x | | x |
| Researcher prepares research documents | | | x | | x |
| Researcher reviews research results with clients | | | | x | x |
| **Resources** | | x | x | x | x |
| **Objectives** | x | x | x | x | x |
| "x" represents the relationship between the sample clauses of ISO 45001 and the laboratory's MS. | | | | | |

## Table 5.3: Mapping ISO 9001 requirements against CSL2 MS

| | ISO 9001: 2015 Sample Clauses | | | | |
|---|---|---|---|---|---|
| **CSL2 MS Elements** **Processes** | **8.2 Requirements for products and services** | **8.3 Design and development** | **9.1 Monitoring, measurement, analysis and evaluation** | **9.2 Internal audit** | **9.3 Management review** |
| Clients contact laboratory experts | x | | | | x |
| Clients explain requirements of research to laboratory director | | | | | x |
| Laboratory director analyzes client's requirements | x | x | x | | x |
| Laboratory director prepares research proposal | x | x | | | x |
| Researcher performs machining of parts or prototype | x | x | x | | x |
| Researcher inspects parts or prototype | x | x | x | x | x |
| Client reviews parts or prototype | x | | | | |
| Researcher applies corrective actions | x | x | x | x | x |
| Researcher manufactures final parts or prototype | x | x | | x | x |
| **Resources** | | x | x | x | x |
| **Objectives** | x | x | x | x | x |
| "x" represents the relationship between the sample clauses of ISO 9001 and the laboratory's MS. | | | | | |

## 5.4 Incorporate MSS requirements into CSLs MS [IUMSS, 3.5]

### 5.4.1 Identify and analyze gaps

After establishing the relationships between the CSLs MSs and the MSSs requirements in the previous section, the next step for implementing the selected MSSs is to identify and understand how far the CSLs are from fulfilling these requirements. Tables 5.4 and 5.5 show the gap analysis for CSL1 and CSL2 and detail the level of fulfillment of the MSS's requirements. These tables also present the necessary activities, procedures, or resources that need to be modified or added to eliminate the gaps.

As suggested in the IUMSS handbook (ISO, 2018e, p. 72), colour-coding is used in Tables 5.4 and 5.5 to illustrate the level of compliance with the requirements:

- Green: Full compliance.
- Yellow: Partial compliance.
- Red: Non-compliance.

**Table 5.4: CSL1 gap analysis**

| ISO 45001 | GAP | Suggested Action |
|---|---|---|
| 8.1.1<br>8.1.4 | Currently, some operational controls are in place, but their effectiveness is not verified systematically. | • The laboratory's director needs first to establish the OH&S objectives, allocate resources, and then implement the processes necessary to fulfill these objectives. Once the processes are implemented for the OH&S MS, this gap will be closed.<br>• For the procurement of resources, the implementation of a checklist for the materials, supplies and other goods to verify that they are in good condition before their use during the research experiments should be considered.<br>• The lab director and researchers assess the laboratory risks and document them in a Risk Register (see Figure 5.5). |
| 8.1.2 | There is not a formal process for the elimination of hazards and risks. | • Draw a flowchart for the elimination and reduction of risk process that follows the hierarchy of controls.<br>• The lab director and researcher verify the effectiveness of the controls identified in the Risk Register through lab inspections and audits. |
| 8.1.3 | There is not a process for the management of change. | Draw a flowchart that explains the "management of change" process. |
| 8.2 | The CSL has an emergency plan and procedure. | Verify that emergency plans are updated. |

## Table 5.4 (continued): CSL1 gap analysis

| ISO 45001 | GAP | Suggested Action |
|---|---|---|
| 9.1.1 | The CSL performs radiation measurements for visitors and personnel who enter the laboratory facility | Once the processes for the OH&S MS are implemented, identify other necessary measurements to be done and write a simple instruction to document it. |
| 9.1.2 | The CSL does not evaluate compliance with legal requirements | Create a written instruction for assessing compliance and assign a person responsible for doing it. |
| 9.2 | There CSL does not conduct internal audits | Schedule internal audits and incorporate them into the laboratory procedure. |
| 9.3 | Currently, the laboratory review the results from research | Incorporate relevant information of OH&S performance into the management review meetings.<br>Add the management review activity to the process flowchart. |

## Table 5.5: CSL2 gap analysis

| ISO 9001 | GAP | Suggested Action |
|---|---|---|
| 8.2.1 | There is communication with customers at the first meeting and during the research project. | None. |
| 8.2.2 | The requirements for the research project are established in the first meeting and are documented in the research agreement. | None. |
| 8.2.3 | | None. |
| 8.2.4 | In case of a change of the research project requirements, the clients inform the laboratory director directly. The laboratory director then informs the researchers. | None. |
| 8.3 | There is no formal process of design of the research. | Develop a flowchart that illustrates the design and development process for a research project. |
| 9.1.1 | Although the CSL monitors the tests and performs measurements on the samples, no document specifies when and how to perform the monitoring and measurements. | Write a procedure that specifies what and when needs to be monitored and measured and the methods used for that. |
| 9.1.2 | The CSL receives feedback on finished products and services from the customers. However, there is no formal process to monitor and review the customer's satisfaction. | Keep a record of the feedback on a spreadsheet and analyze the information regularly. |
| 9.1.3 | Each research group analyzes and evaluates its own data, and this information is captured in different research reports. | None. |
| 9.2 | The CSL does not conduct internal audits. | Schedule internal audits and incorporate them into the laboratory procedure. An audit schedule for cross audits in CLS 2 is shown in Figure 5.3. |
| 9.3 | Currently, the laboratory only reviews the results from research. | Incorporate quality objectives and performance plans into the management review meetings. |

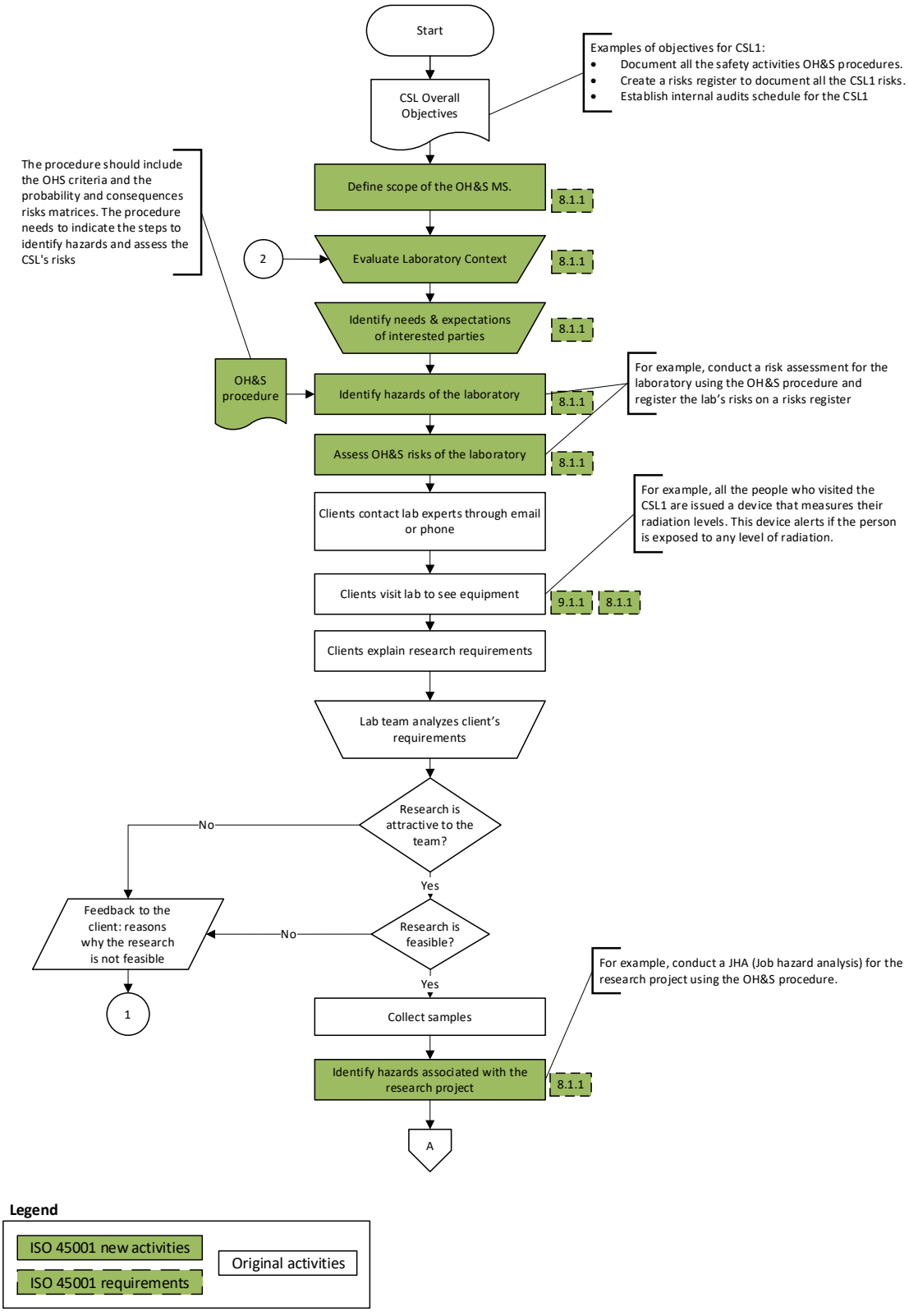
### 5.4.2 Close gaps

Tables 5.4 and 5.5 show the identified and analyzed gaps in the second column and present suggested actions that need to be performed to fulfill the MSSs requirements in column three.

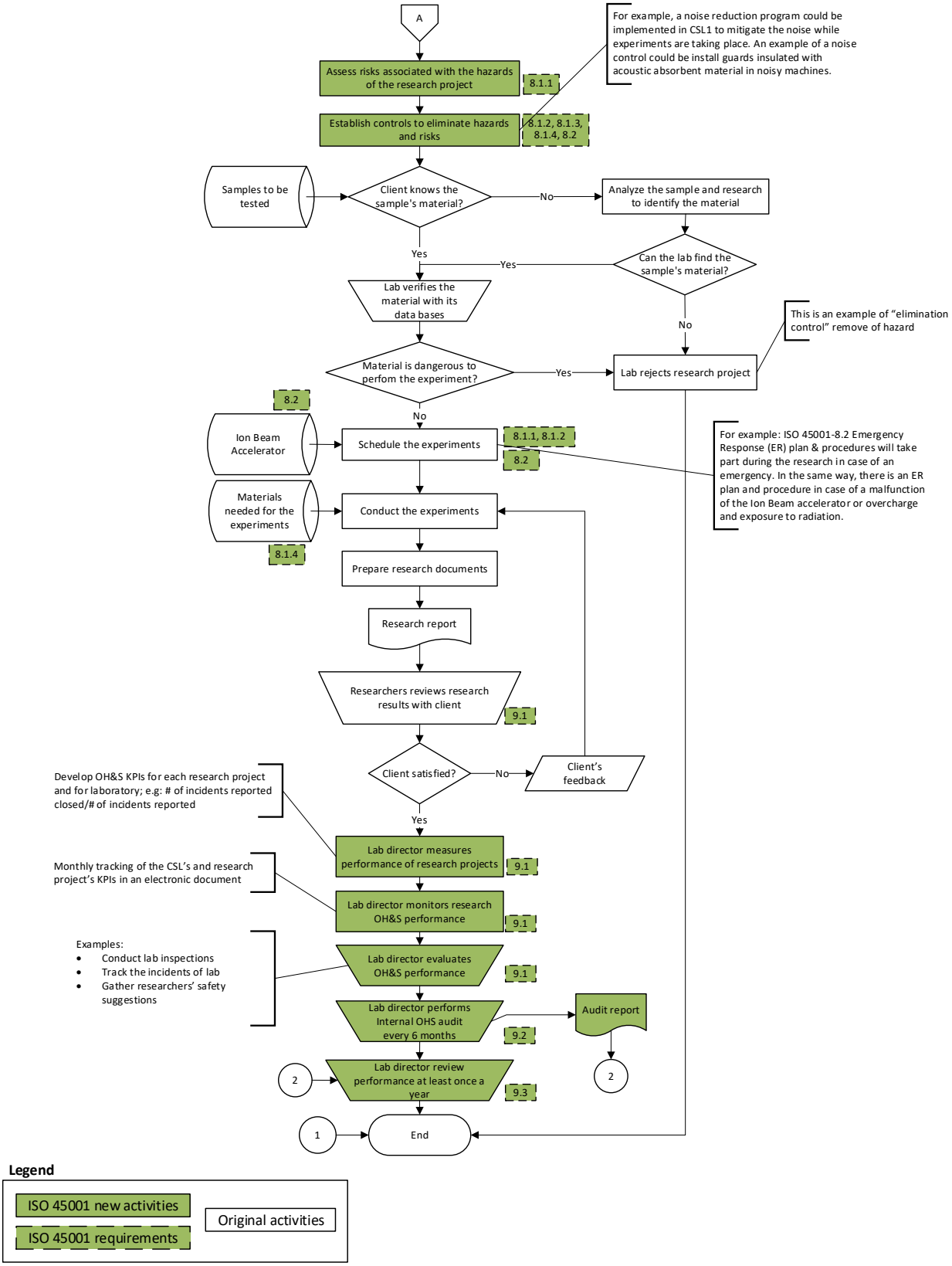
To close the identified gaps, it is necessary to perform some activities, such as those described in Tables 5.4 and 5.5. In some cases, there will be a need to add more processes and resources, but in others, just adding a simple procedure or performing training will be enough to comply with the requirements.

Figures 5.1 and 5.2 show the processes that need to be implemented to fulfill the MSSs requirements and are depicted in different colours: light green for ISO 45001 and yellow for ISO 9001.

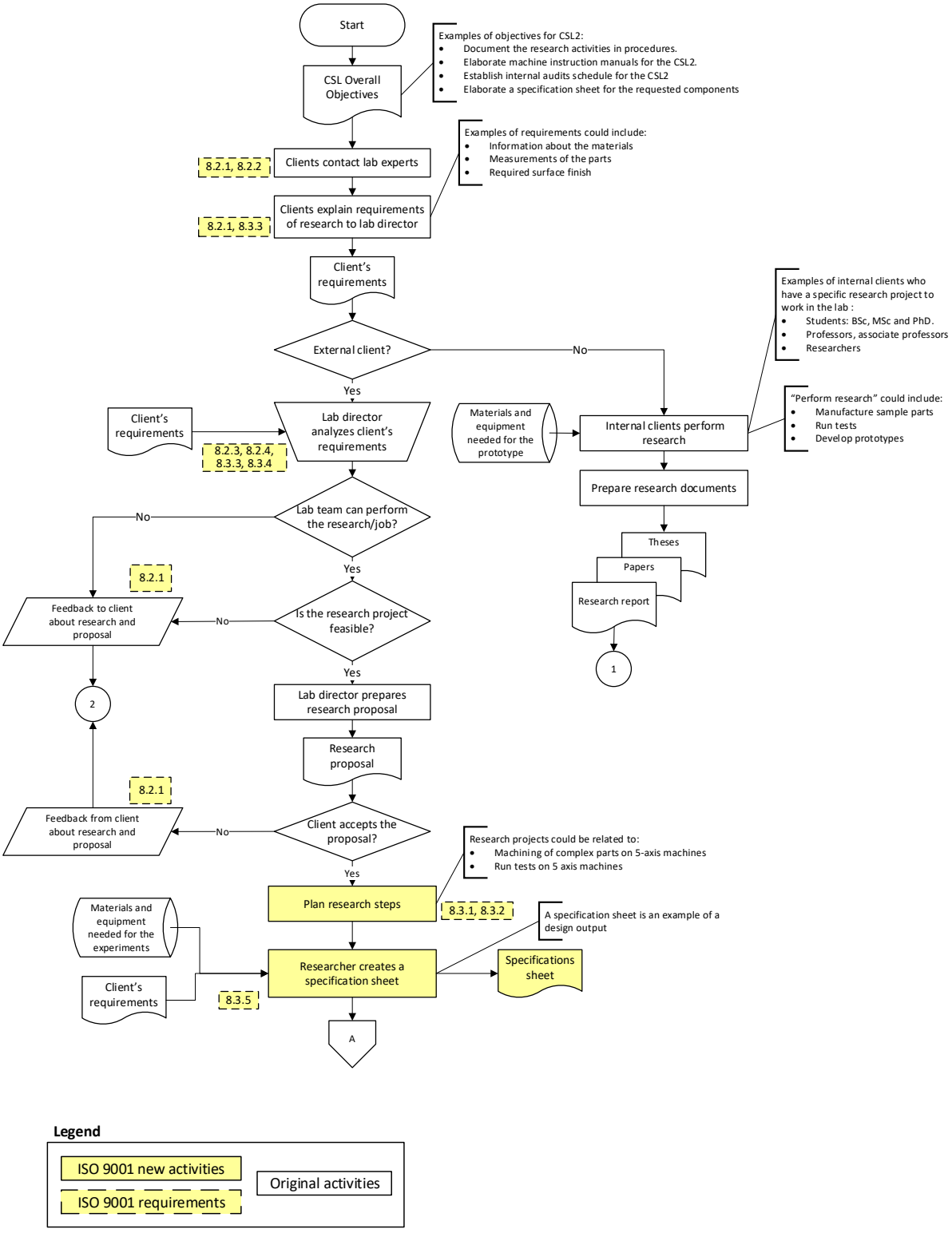
## Figure 5.1: CSL1 Standardized MS flowchart



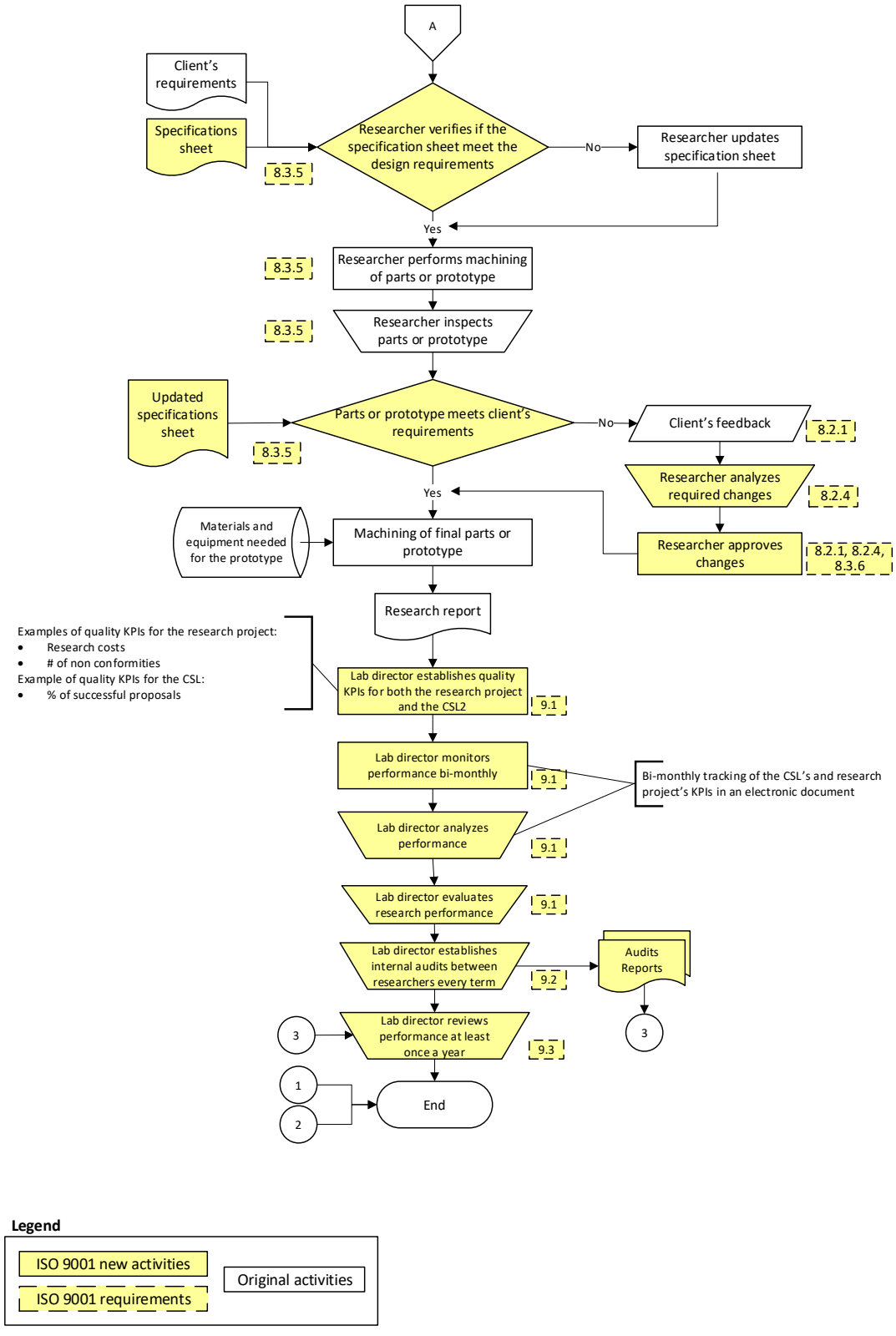
## Figure 5.1 (continued): CSL1 Standardized MS flowchart



## Figure 5.2: CSL2 Standardized MS flowchart



## Figure 5.2 (continued): CSL2 Standardized MS flowchart



### 5.4.3 Verify gap closure

Three examples are presented in this section to illustrate the verification of gap closure. One for the common requirement of both MSSs and one for a specific requirement of each of the two MSSs:

- 9.2 "*Internal audit*," which is a common requirement of ISO 9001 and ISO 45001
- 8.1 "*Operational planning and control*" for ISO 45001 in CSL1 and,
- 8.3 "*Design and development*" for ISO 9001 in CSL2.

#### 5.4.3.1 Internal Audit

For both MSSs, the sub-clause requirements are almost the same. Sub-clause 9.2.1 requires checking if the CSLs comply with their MSSs requirements (ISO 45001 for CSL1 and ISO 9001 for CSL2). It also requires verifying if the MSs are implemented and maintained. Sub-clause 9.2.2 requires establishing a programme for internal audits.

According to the information obtained through the questionnaire application, both CSLs do not perform internal audits. For that reason, new processes were suggested and are depicted in Figures 5.1 and 5.2. These processes will need some specific steps that should be stated in a procedure to address the planning, resources, training and documents necessary. This procedure should also specify what to do with the audit results (findings) and how to incorporate them into the improvement process according to clause 10.2 of ISO 9001.

As part of audit planning, the first step will be choosing the people to train for acquiring the competencies needed as internal auditors following clause 7.2.3 of ISO 19011. In CSL1, the most suitable person to be trained would be the researcher in charge of the laboratory's safety. Similarly, in CSL2, senior researchers and research coordinators from each machine group would be chosen for the internal auditors training.

Another interesting aspect in terms of the audit program can be seen in CSL2. Since it is a large facility with different research projects conducted parallel, internal cross audits can be scheduled. Cross audits would be beneficial to bring fresh eyes to help identify areas of processes that might not be evident to the people who work there continually. An example of an internal cross audit schedule for CSL2 is shown in Figure 5.3.

**Figure 5.3: CSL2 - Internal Cross Audits Schedule**

| CSL2 - Internal Cross Audits Schedule | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Research stations** | **Auditee** | **Auditor** | | | | **Audit criteria** | |
| | | | | | | **ISO 9001 Requirements** | **Lab Procedures** |
| | | **RC1** | **RC2** | **RC3** | **RC4** | | |
| 5-axis Machining | Resarch coordinator 1 (**RC1**) | - | Jan-Apr | May-Aug | Sep-Dec | | |
| Welding | Resarch coordinator 2 (**RC2**) | Jan-Apr | - | Sep-Dec | May-Aug | | |
| Measuring systems | Resarch coordinator 3 (**RC3**) | Sep-Dec | May-Aug | - | Jan-Apr | | |
| 3D Modelling (printing & scanning) | Resarch coordinator 4 (**RC3**) | May-Aug | Sep-Dec | Jan-Apr | - | | |

| Possible Audit Findings | |
|---|---|
| GP | Good Practice |
| IO | Improvement Opportunity |
| NA | Not Audited |
| MA | Mayor Non-conformance |
| MI | Minor Non-conformance |

### 5.4.3.2 Operational planning and control for ISO 45001 in CSL1

Sub-clause 8.1.1 refers to having in place processes and ensuring that they meet the CSL1's OH&S objectives. Sub-clause 8.1.2 refers to eliminating hazards and reducing OH&S risks by applying the hierarchy of controls. Sub-clauses 8.1.3 and 8.1.4 refer to the correct management of change and procurement, respectively.

Based on the information obtained through interviews and the visits performed at the CSL1, it could be observed that the laboratory has some controls in place to address the risks derived from the ion beam technology (e.g., radiation measurements for people who enter the laboratory facility and hazardous waste disposal). However, there is not a process to verify the effectiveness of such controls. In addition, no evidence could be found that the CSL1 follows the hierarchy of controls to eliminate hazards and reduce OH&S risks. For that reason, new processes were recommended to be added and are depicted in Figure 5.1.

The first three processes can be addressed with a written procedure that should include the context of the laboratory, the needs and expectations of the interested parties and the scope of the OH&S MS. This procedure should also identify the criteria to be used in the OH&S MS (e.g., risk matrixes to be used, frequency of audits and inspections). An example of a risk matrix is presented in Figure 5.4. This matrix was adapted from Otto (2021) by modifying the risk ratings and their

colours. For the fourth process, a procedure that clearly states how to use the hierarchy of controls and maintain those controls can be developed. Another helpful tool for this process can be an OH&S Risk Register that can help verify that these controls are updated and maintained. An example of this register is presented in Figure 5.5. This register was developed using a sample of the hazards of the List of Hazards presented in Otto (2021) for particle accelerator facilities. The OH&S controls proposed in the register were also selected from Otto (2021).

**Figure 5.4: Risk Matrix**

| | | Severity | | |
|---|---|---|---|---|
| | | **Slightly harmful (1)** | **Harmful (2)** | **Extremely harmful (3)** |
| **Probability** | **Highly unlikely (1)** | Low (1) | Low (2) | Medium (3) |
| | **Unlikely (2)** | Low (2) | Medium (4) | High (6) |
| | **Likely (3)** | Medium (3) | High (6) | High (9) |

**Figure 5.5: Risk Register for CSL1**

| CSL1 OH&S RISKS REGISTER | | COMPLETED BY: Lab Director | | | | DATE: | | |
|---|---|---|---|---|---|---|---|---|
| **HAZARD IDENTIFICATION** | | **RISK ASSESSMENT** | | | **CONTROL METHOD** | **REVIEW** | | |
| **Hazards** | **Risks** | **Likelihood** | **Severity** | **Risk rating** | **Controls** | **Additional controls** | **Review period** | **By whom** |
| Ionizing radiation (Otto, 2021, pp. 67). | Tissue reactions due to exposure (Otto, 2021, pp. 65). | Highly unlikely (1) | Extremely harmful (3) | Medium (3) | • Lab personnel and visitors use a personal radiation dosimeter (Otto, 2021, pp. 67).<br>• A designated person locks access doors before starting the accelerator (Otto, 2021, pp. 67). | Annual calibration of dosimeters. | Annually | Lab director |
| | | | | | | Verify behaviour through inspections. | Monthly | Lab director |
| | Cancer due to chronic exposure (Otto, 2021, pp. 65). | Unlikely (2) | Extremely harmful (3) | High (6) | • People can only enter the accelerator area if registered in a list of authorized personnel or have received permission to do so (Otto, 2021, pp. 133).<br>• Prevent accelerator operation as long as personnel are present in the accelerator area (Otto, 2021, pp. 79). | Verify behaviour through inspections. | Monthly | Lab director |
| | | | | | | Peer double-check to make sure that nobody is present in the accelerator area before releasing it. | Daily | Researchers |
| Physical hazard - Field, magnetic (Otto, 2021, pp. 142). | Injuries caused by projected metallic objects (Otto, 2021, pp. 17). | Unlikely (2) | Harmful (2) | Medium (4) | • Hand-held metal detector in facility entrance.<br>• Ferromagnetic, metallic objects are banned from the accelerator area during operation (Otto, 2021, pp. 18). | Annual calibration. | Annually | Lab director |
| | | | | | | Peer double check | Daily | Researchers |
| | Medical devices malfunction (Otto, 2021, pp. 17). | Unlikely (2) | Extremely harmful (3) | High (6) | Put warning signs at the entering of the accelerator area (Otto, 2021, pp. 17). | Maintain the signs | Monthly | Researchers |

#### 5.4.3.3 Design and development for ISO 9001 in CSL2

Six sub-clauses detail the requirements regarding design and development. Sub-clause 8.3.1 talks about the necessity of a design and development process. Sub-clause 8.3.2 refers to

design and development planning, which asks for a plan on how to create the designs. For CSL2, the design and development activities, including the planning, are suggested and depicted in yellow in Figure 5.2. However, to capture most of the process and include the responsibilities for each activity, a written procedure could be developed even when the MSS does not require it. This recommendation aligns with Krapp (2001), who indicates that high-quality documentation may help decrease the negative impact of the high staff turnovers that characterize university research laboratories.

Sub-clause 8.3.3 refers to the necessary inputs for the design and development. A procedure should specify how to gather all the requirements needed for the design (i.e., inputs) from the perspective of the customer (e.g., materials and specifications), specific industry requirements (e.g., standards) and legal requirements. The procedure should also state how to keep records of these inputs. CSL2 could use a template to capture these inputs, which could be a part of the procedure. This template would support the traceability aspect of the QMS, increasing the transparency in research projects (Krapp, 2001; Biasini, 2012; Littrell et al., 2019; Outaki et al., 2019; Estienne et al., 2020) and the reliability of the results (Krapp, 2001; Mathur-De Vré, 2000; Presot et al., 2014; Littrell et al., 2019).

Sub-clause 8.3.4 discusses the implementation of controls for the design and development process, especially in terms of review, verification and validation. All these steps are considered in the suggested process in Figure 5.2 and need to be included in the procedure. For example, for the review, the procedure needs to state how to verify if the design meets the client's requirements by using checklists or receiving formal approval by email and the recording method.

Sub-clause 8.3.5 refers to the design and development outputs. Poli et al. (2015) point out that one of the characteristics of research laboratories that has to be taken into account when implementing a QMS is the intangible nature of the outcomes. In CSL2, the outputs are, for example, the drawings of the prototype or samples, the programming codes for the machines or test guidelines. The outputs need to meet all the inputs requirements and meet the acceptance criteria for production. The fulfillment of these criteria could be verified, for example, using a checklist.

Finally, sub-clause 8.3.6 talks about the design and development changes. For CSL2, a register of the changes applied to outputs and the necessary steps for the approval should be

considered in the procedure. For example, having the signature of all people involved in the changes may be required for output approval. The requirements of this clause are critical because it was identified through the interviews that there seem to be frequent last-minute changes to the prototypes and samples that lead to delivery delays.

## 5.5 Summary

This chapter presented the applicability of the IUMSS methodology for the implementation of ISO 45001 and ISO 9001 requirements into the CSL1 and CSL2 MSs, respectively.

Sub-chapter 5.2 showed the leading, the determination of the scope and a basic plan for the implementation process.

Sub-chapter 5.3 presented the connection between the MSSs requirements and the CSL's MS. This sub-chapter covers the structuring of the CSLs MSs (5.3.1), structuring of the MSSs requirements (5.3.2), with three common and two specific requirements used, and mapping (5.3.3). In section 5.3.3, the "*matrix*" approach (ISO, 2018e) was used to show the relationships between the requirements and the MSs elements.

Sub-chapter 5.4 described how the new MSS requirements could be incorporated into the CSLs current MSs. This incorporation process included the gap identification and analysis (5.4.1), where colour coding was used to show the level of compliance with the requirements, gap closure (5.4.2), where updated flowcharts showed the inclusion of new processes that fulfilled the standard provisions and gap closure verification (5.4.3).

# 6 IUMSS Methodology: Integration

## 6.1 Introduction

This chapter presents the integration of two MSSs into two of the CSL's MSs by applying the IUMSS methodology: ISO 10001 and ISO 10002 for CSL3 and ISO 10002 and ISO 45001 for CSL4.

Similar to Chapter 5, the IUMSS methodology is followed, and the guiding questions suggested in Chapter 3 of this methodology are answered.

## 6.2 Lead, determine the scope and plan the integration [IUMSS, 3.1-3.3]

Regarding the leadership for the integration, CSL3 is similar to CSL1 and CSL2, where the laboratory directors are responsible for providing the leadership and necessary direction. Still, they need to seek approval from the general director, who manages all the laboratories on the university campus. For CSL4, the laboratory director can decide to integrate the MSs because of more independence in the management of the laboratory.

The scope for integration is to apply ISO 10001 and ISO 10002 into CSL3, and ISO 45001 and ISO 10002 into CSL4. The plan is to implement both standards (i.e., ISO 10001 and 10002) entirely in CSL3, which means applying all the requirements simultaneously in an integrated way. In CSL4, all the clauses of ISO 10002 are integrated with some of the clauses of ISO 45001. The chosen clauses are shown in section 6.3.2 of this thesis.

## 6.3 Connect MSSs requirements with the CSLs MSs [IUMSS, 3.4]

### 6.3.1 Structure MSs

The CSLs MSs were represented in flowcharts shown in Figures 4-3 and Figure 4-4 in Chapter 4. These flowcharts illustrate the interrelationships and the interdependencies among the processes and help understand each laboratory's MS.

### 6.3.2 Structure MSSs requirements

As previously discussed in section 4.2, the CSLs selected to illustrate the integration process did not have implemented any MSSs. In addition, the scope for the integration in both

CSLs involves two MSSs. Therefore, the MSSs requirements to integrate into the two CSLs MSs fall in scenario "3a" stated in the IUMSS handbook, on page 48, specifically, the implementation of new multiple MSSs and the integration of their requirements into the MS with no previously-implemented MSSs.

In CSL3, the requirements of ISO 10001 and ISO 10002 will be fully integrated. As both standards have a similar structure, it would be straightforward to incorporate them into the MS.

For CSL4, all the requirements of ISO 10002 will be integrated with five clauses of ISO 45001 as an example. The selected requirements are part of the different elements of the ISO 45001 standard. Three clauses, common to other MSSs according to the HSL (9.1, 9.2 and 9.3), and two clauses that are ISO 45001 specific (8.1 and 8.2) were selected for integration. These common and specific clauses are the same that were used for the standardization process in CSL1 in Chapter Five. The reason for this selection is to study the use of one standard in particular (i.e., ISO 45001) in two different CSLs for both standardization and integration processes. This process comparison will be covered in section 7.4. In addition, CSL4 performs activities that cover most of the previously chosen requirements (common and specific) except for the internal audit. Table 6.1 summarizes the requirements applied for each CSL.

**Table 6.1: MSS Requirements for Integration**

| REQUIREMENTS TO BE IMPLEMENTED IN EACH CSL FOR INTEGRATION | | |
|---|---|---|
| **MSS** | **CSL3** | **CSL4** |
| **ISO 10001** | All clauses | N/A |
| **ISO 10002** | All clauses | All clauses |
| **ISO 45001** | N/A | 8.1 Operational planning and control<br>8.2 Emergency preparedness and control<br><br>9.1 Monitoring, measurement, analysis and performance evaluation<br>9.2 Internal audit<br>9.3 Management review |
| **Note:** "N/A" indicates that a specific standard will not be implemented in that laboratory as a part of this thesis. | | |

### 6.3.3 Mapping MSS requirements against the CSLs MSs

The "*matrix*" or tabular approach (ISO, 2018e) was used in Section 5.3.3 for the mapping process. The juxtaposition approach is used in this section to illustrate a different method for integration mapping. The juxtaposition approach is a graphical representation of the relationships between the MSSs requirements intended to be integrated and the CSLs MSs (ISO, 2018e). The connections between the laboratory's processes and the requirements of ISO 10001 and ISO 10002 are illustrated in Figure 6.1. In this figure, the requirement clause numbers are placed over processes and elements impacted by these clauses.

Figure 6.1 shows the juxtaposition mapping approach in CSL3, and Figure 6.2 presents that approach for CSL4. For both cases, the elements of the CSLs MSs like objectives, processes and resources are illustrated in a flowchart. Over the flowchart, clause numbers are depicted as dotted rectangles in different colours depending on the MSS: light blue for ISO 10001 and light orange for ISO 10002 in CSL3; light blue for ISO 45001 and light orange for ISO 10002 in CSL4.

**Figure 6.1: Mapping ISO 10001 and ISO 10002 against CSL3 MS using juxtaposition**

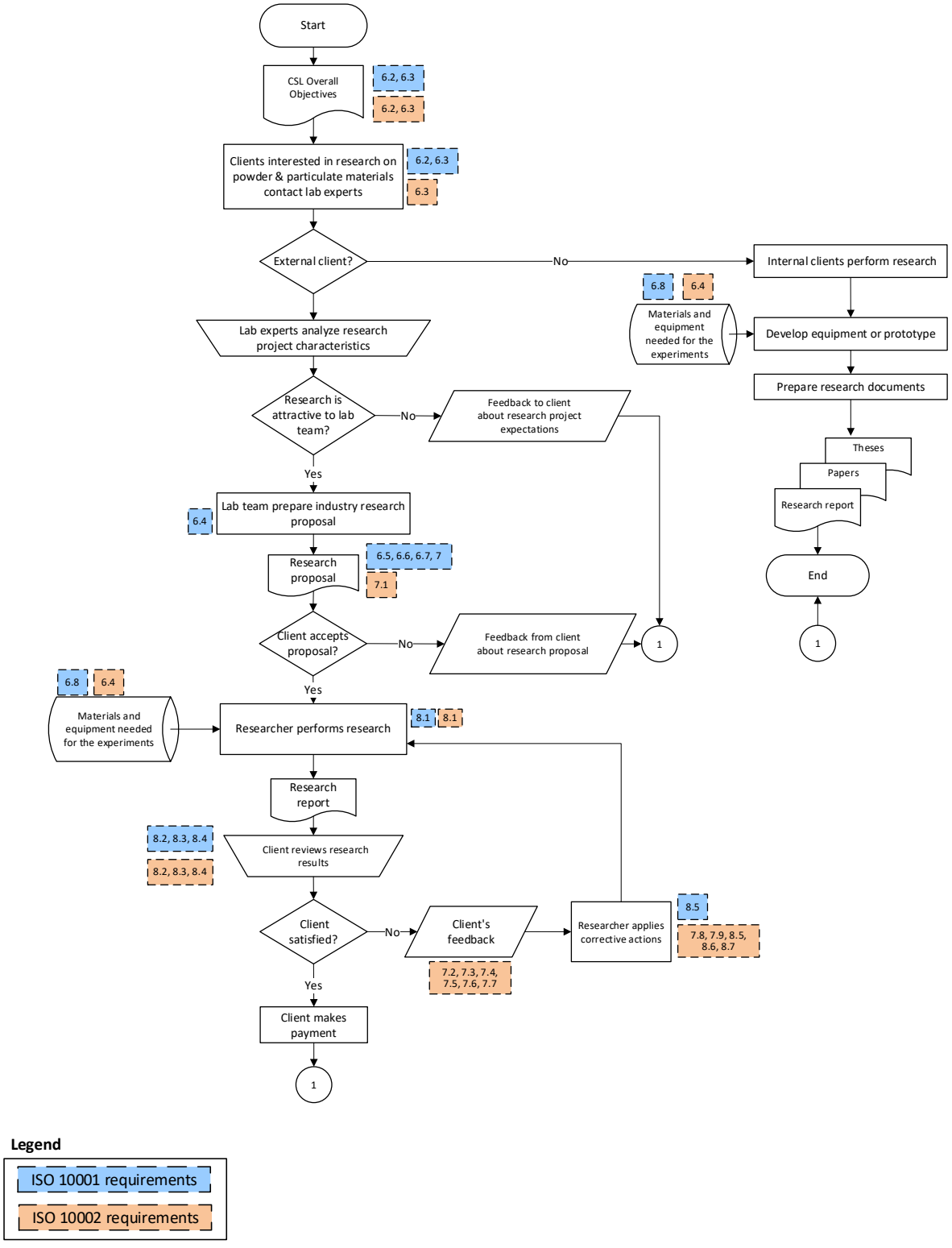


**Figure 6.2: Mapping ISO 45001 and ISO 10002 against CSL4 MS using juxtaposition**

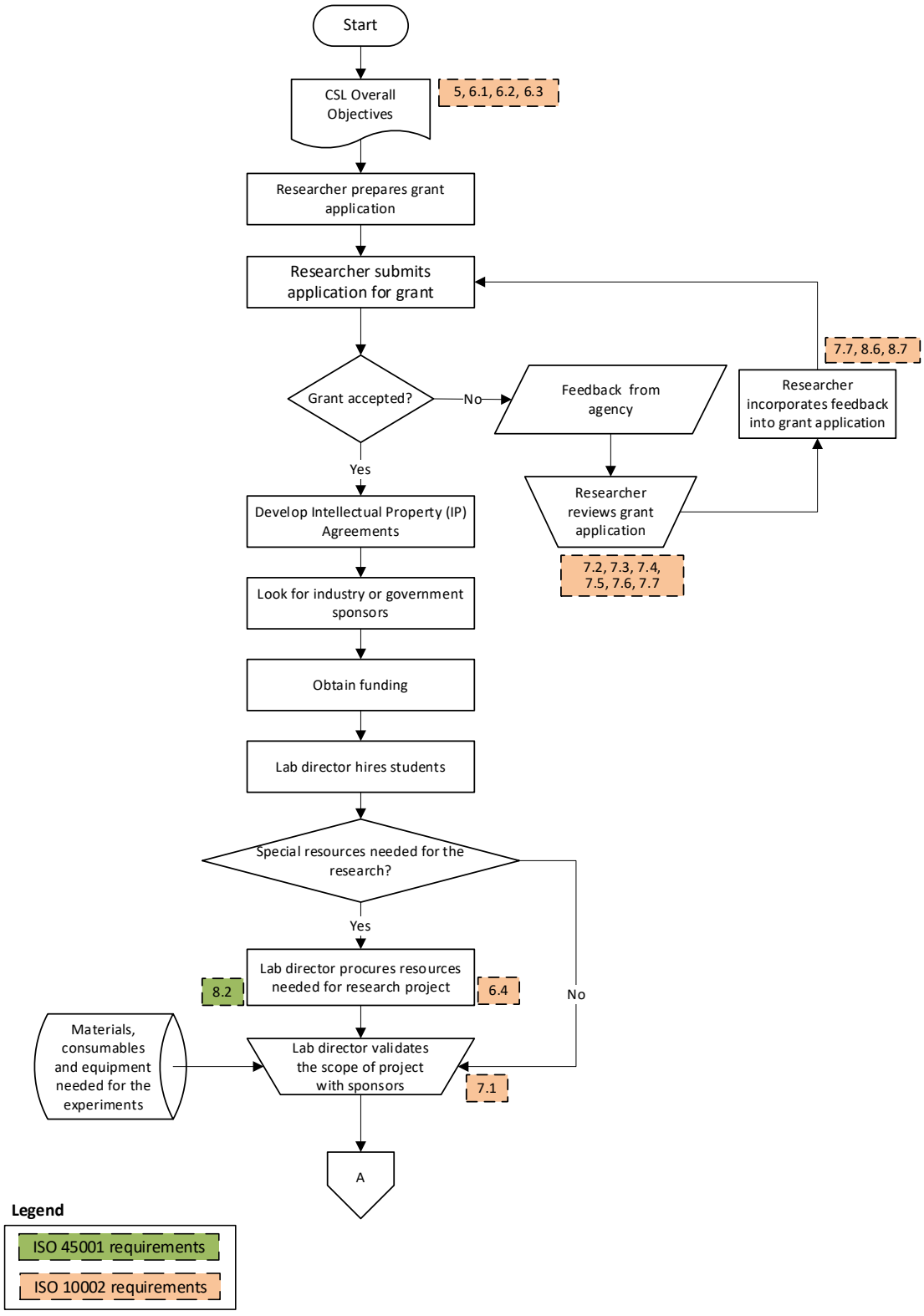
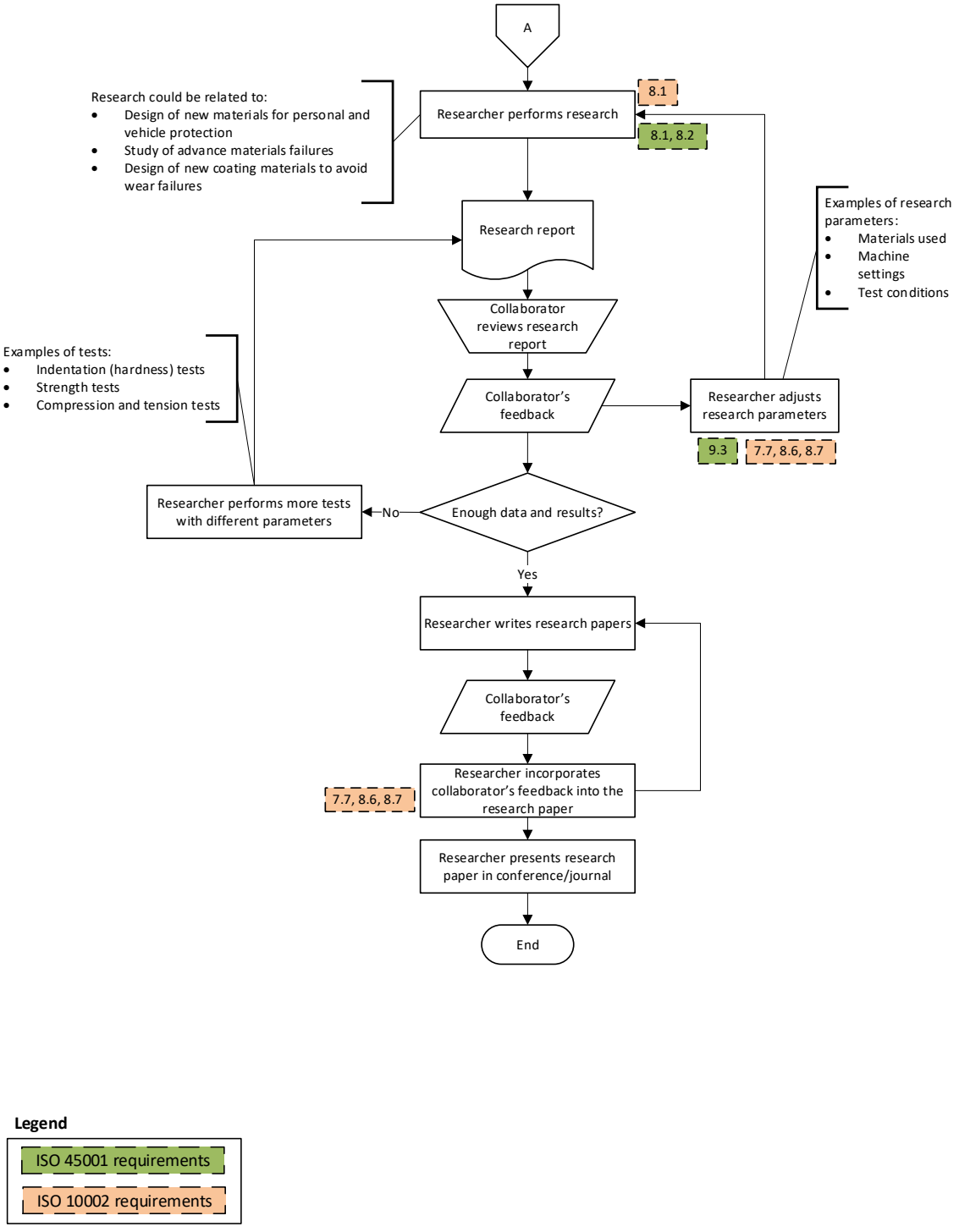


**Figure 6.2 (continued): Mapping ISO 45001 and ISO 10002 against CSL4 MS using juxtaposition**



## 6.4 Incorporate MSS requirements into CSLs MS [IUMSS, 3.5]

### 6.4.1 Identify and analyze gaps

Tables 6-2 and 6-3 show the gap analysis results in CSL3 and CSL4.

**Table 6.2: CSL3 gap analysis**

| ISO 10001 | ISO 10002 | GAP | Suggested Action |
|---|---|---|---|
| 4, 5.2 | 4, 5.2, 5.3 | Currently, no process addresses these requirements. | The laboratory's director should develop and implement a policy that shows its commitment to the guiding principles of the code and feedback-handling process and ensures the framework and the resources needed. |
| 6.1 | 6.2 | There are no objectives to achieve regarding the MSSs. | Develop objectives regarding customers' satisfaction, e.g.:<br>• Code: Develop a satisfaction code to enhance the research collaborator's confidence regarding the research's progress.<br>• Feedback-handling: Start recording feedback from industry clients through monthly research reports for the project and build statistics. |
| 5.1, 6.2, 6.3 | 5.1 | The current process of meeting with clients only gathers information related to the research. It does not include information from other internal relevant parties like researchers or university authorities. | • Implement the management review process where the laboratory director and interested parties collect relevant information for the implementation of the MSSs.<br>• Organize meetings with internal (students, researchers and professors) and external (industry clients from the chemical, food, pharmaceutical and consumer goods industries) interested parties to get feedback, such as issues with research and clients or challenges to overcome. |
| 6.4 | | The laboratory does not have a code. | Implement the process to prepare and review the code, e.g.: *"A research's progress report will be sent to the customer within the first week of the upcoming month (the first month after the end of the month when the report is done), or the laboratory director will provide an explanation and a progress presentation at the customer's facility. This code is valid for the entire duration of the research project. The delivery of the progress report cannot be guaranteed during holidays or in cases of natural or technical events outside of the control of the laboratory. Please inform the laboratory director of any concern or feedback through email or phone."* |
| 6.5 | | As there is no code, there are no indicators. | Develop performance indicators for the code (e.g., % of on-time research reports sent to the customer). |
| 6.6, 6.7 | 5.4 | These processes do not exist. | Include the code (section 6.4.3.1) and the flowchart of the FHP in the research agreement so external clients are informed. |
| 6.8 | 6.4 | With the current resources, it is possible to address the MSSs. | • Assess the resources needed to implement the code and the feedback handling process.<br>• The resources, in this case, are not much different than they already have, for example, computers, email and phone, to answer the feedback. |

## Table 6.2 (continued): CSL3 gap analysis

| ISO 10001 | ISO 10002 | GAP | Suggested Action |
|---|---|---|---|
| 7 | 6.1, 6.3, 7 | These processes do not exist and need to be implemented. | • Prepare and send the Monthly Research Report to the collaborator, which contains the survey to measure satisfaction with code and FHP.<br>• Train laboratory personnel on the code and the feedback handling process through a workshop. |
| 8.1, 8.2, 8.3 | 8.1, 8.2, 8.3 | | • Implement a process to analyze the code and the feedback handling process feedback and information.<br>• Develop and run a survey to assess satisfaction with the code and the feedback-handling process.<br>• The survey could be developed using online resources such as Google forms (Figure 6.5). |
| 8.4, 8.5 | 8.4, 8.6, 8.7 | | • Review customers' surveys and feedback.<br>• Apply corrective actions and improve the code (e.g., add new information into the Monthly Research Report) and the feedback handling process with relevant feedback. |
| | 8.5 | | Prepare an action plan to audit the code and the feedback-handling process. |

## Table 6.3: CSL4 gap analysis

| ISO 10002 | ISO 45001 | GAP | Suggested Action |
|---|---|---|---|
| 4 | | The CSL4 does not have a feedback-handling process in place. | The laboratory director should evidence his commitment to the feedback-handling process's guiding principles (FHP) by stating this commitment in the laboratory policy. |
| 5.1, 6.1 | | The CSL mainly gathers information related to the research. It does not include information from other relevant interested parties. | • Identify the relevant interested parties for the CSL MS (e.g. students, collaborators, university authorities.)<br>• Organize meetings with the appropriate interested parties to gather information such as issues with research and clients or risks and opportunities to explore. |
| 5.2, 5.3, 5.4 | | There is no written policy in CSL4. The laboratory director is the leader of the MS. | • The laboratory director should develop a policy that states his commitment to the feedback-handling process and ensure the resources and the framework needed to implement it.<br>• Include input from students and research collaborators in the development of this policy.<br>• This could be addressed by developing a flowchart (Figure 6.6) showing the feedback handling process and a table with the responsibilities the laboratory director and the researchers have in this process (Table 6.5).<br>• Train the people of the laboratory on the flowchart and the code through a workshop. Include information about this flowchart and code during onboard training for new laboratory employees. |
| 6.1, 6.3 | 8.1.1 | There are no processes dedicated to the management of feedback. However, CSL4 follows the general process for the elimination of OH&S hazards and risks from the university. | • Prepare an action plan to implement the feedback handling process.<br>• Draw the new processes flowchart (Figure 6.4) and incorporate it into the current MS, considering all the necessary documents.<br>• Verify the processes in place for the elimination of OH&S hazards and risks. For example, verify if the laboratory's risk assessments are updated and cover all the current research risks. |

**Table 6.3 (continued): CSL4 gap analysis**

| ISO 10002 | ISO 45001 | GAP | Suggested Action |
|---|---|---|---|
| 6.2 | | There are no objectives to achieve regarding the handling of feedback. | Develop objectives regarding the feedback-handling process (e.g., reduce complaints by 30% by implementing a feedback-handling process.) |
| 7.1, 7.2, 7.4, 8.1 | | Currently, there are no processes dedicated to the management of feedback. | • A process should be put in place to receive feedback from collaborators (e.g., through email, during in-person and online meetings).<br>• Depending on the feedback submission method, this feedback would be acknowledged verbally or through a response email.<br>• To monitor the performance of the FHP, the laboratory should record the received and closed feedback to calculate the #feedback closed/#feedback received. |
| 7.3 | | Currently, this process does not exist. | The FHP procedure must state how the feedback would be tracked (e.g., in a spreadsheet). |
| 7.5, 7.6 | | Currently, these processes do not exist. | The feedback-handling process procedure should indicate how to proceed in the initial assessment and the investigation of feedback, depending on the type of feedback (e.g., related to OH&S issues, research parameters, a research paper). |
| 7.7, 7.8, 7.9 | 8.1, 8.2 | CSL4 has some controls in place in terms of safety and follows the general emergency response procedure of the university. However, there are no processes dedicated to feedback management. | • The feedback-handling process procedure should indicate how to respond, communicate and close the feedback. For example, for external clients depending on the feedback, the options for response could be, e.g. rework or change on technical aspects of research, providing more information about the study or offering other kinds of assistance for the collaborators (e.g., additional tests).<br>• The actions could be communicated by email.<br>• Researchers should conduct safety observations according to a schedule to verify the processes used to eliminate OH&S hazards and risks and the emergency response (e.g. risks assessments and OH&S procedures).<br>• CSL4 may consider having specific emergency plans for high risks, e.g. high-pressure impact tests. |
| 8.2, 8.3, 8.4 | 9.1 | CSL4 monitors and measures the performance of the research projects, but it does not consider OHS aspects and feedback. | • Document in a procedure what OH&S aspects are needed to be monitored, measured and analyzed (e.g., the effectiveness of the controls in place for high impact tests on materials.) Risks assessments could be reviewed to that end.<br>• Implement a process to analyze the feedback-handling process (FHP) performance.<br>• Develop and run a survey to assess the satisfaction with the FHP. |
| 8.5 | 9.2 | Currently, these processes do not exist. | Develop a procedure with guidelines for performing internal audits and schedule them. |
| 8.6, 8.7 | 9.3 | Currently, CSL4 only reviews the results of the research projects. | • Incorporate the feedback handling and the OH&S processes into the annual review, including the results from the satisfaction survey.<br>• Apply corrective actions and improve these processes with relevant feedback. |

### 6.4.2 Close gaps

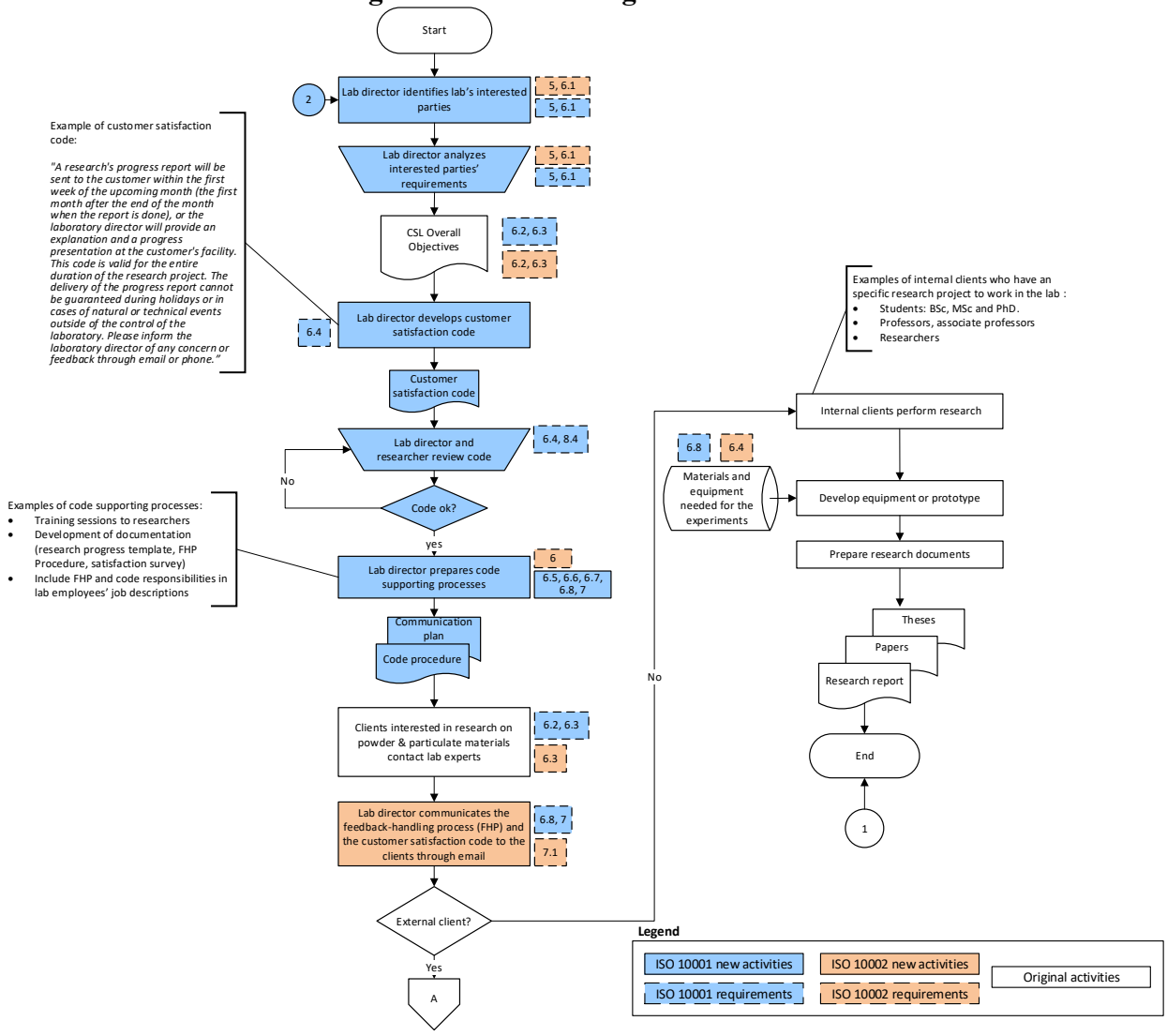
In this step, actions are taken to fulfill the requirements of the MSs. These actions can vary from simply modifying a procedure (e.g., in CSL4 for clause 8.1.1 of ISO 45001, update the

laboratory's risk assessments) to more complex actions like training personnel (e.g., relevant laboratory workers to implement the suggested customer satisfaction code in CSL3). The proposed actions for closing the gaps are presented in Tables 6.2 and 6.3.

### 6.4.2.1 Close Gaps in CSL3 and CSL4

Figures 6.3 and 6.4 show the processes that need to be implemented to fulfill the MSSs requirements. These processes are depicted in different colours in the flowcharts: light blue for ISO 10001, light orange for ISO 10002 in the CSL3; and light green for ISO 45001 and light orange for ISO 10002 in the CSL4.

**Figure 6.3: CSL3 Integrated MS flowchart**



## Figure 6.3 (continued): CSL3 Integrated MS flowchart

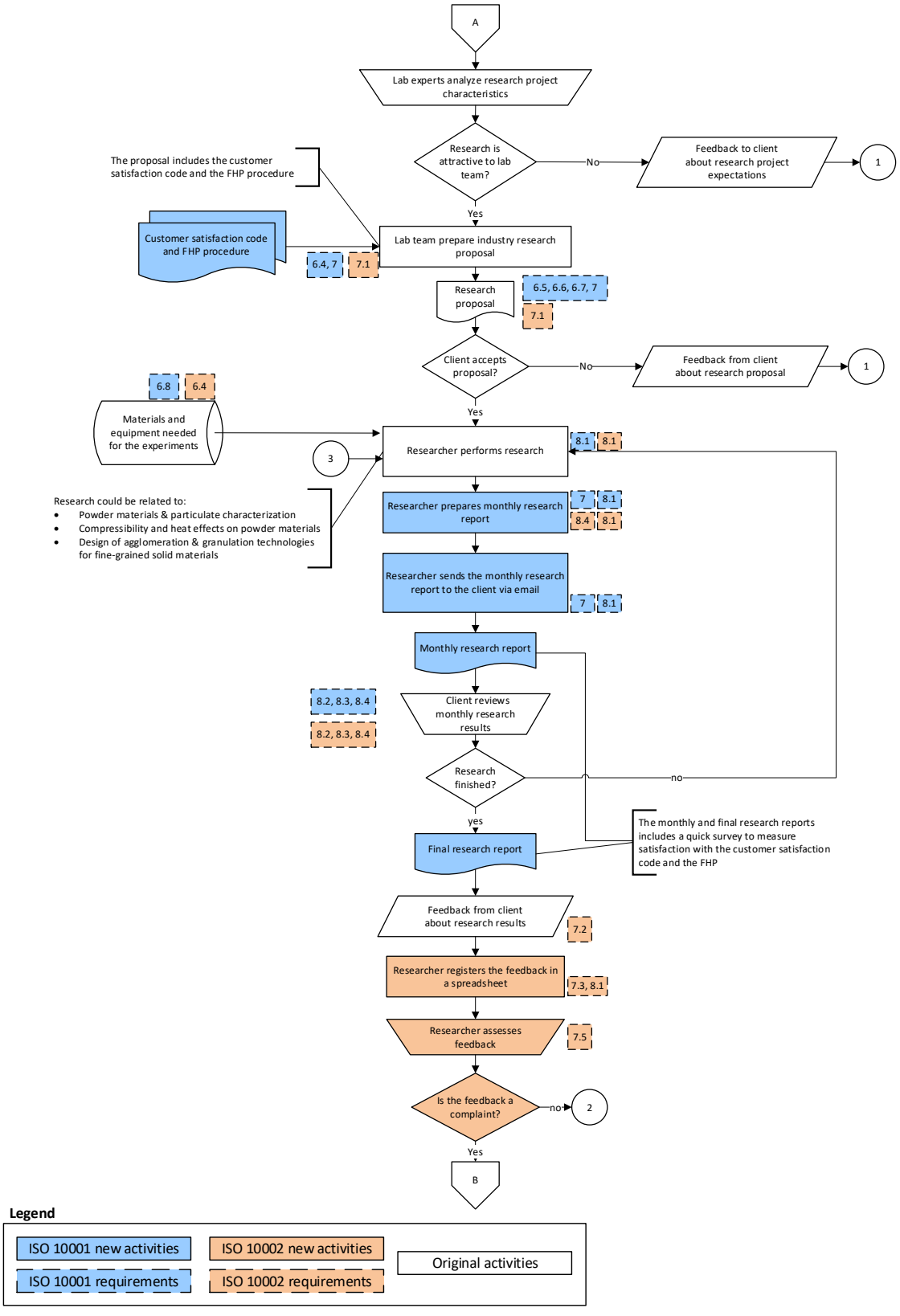
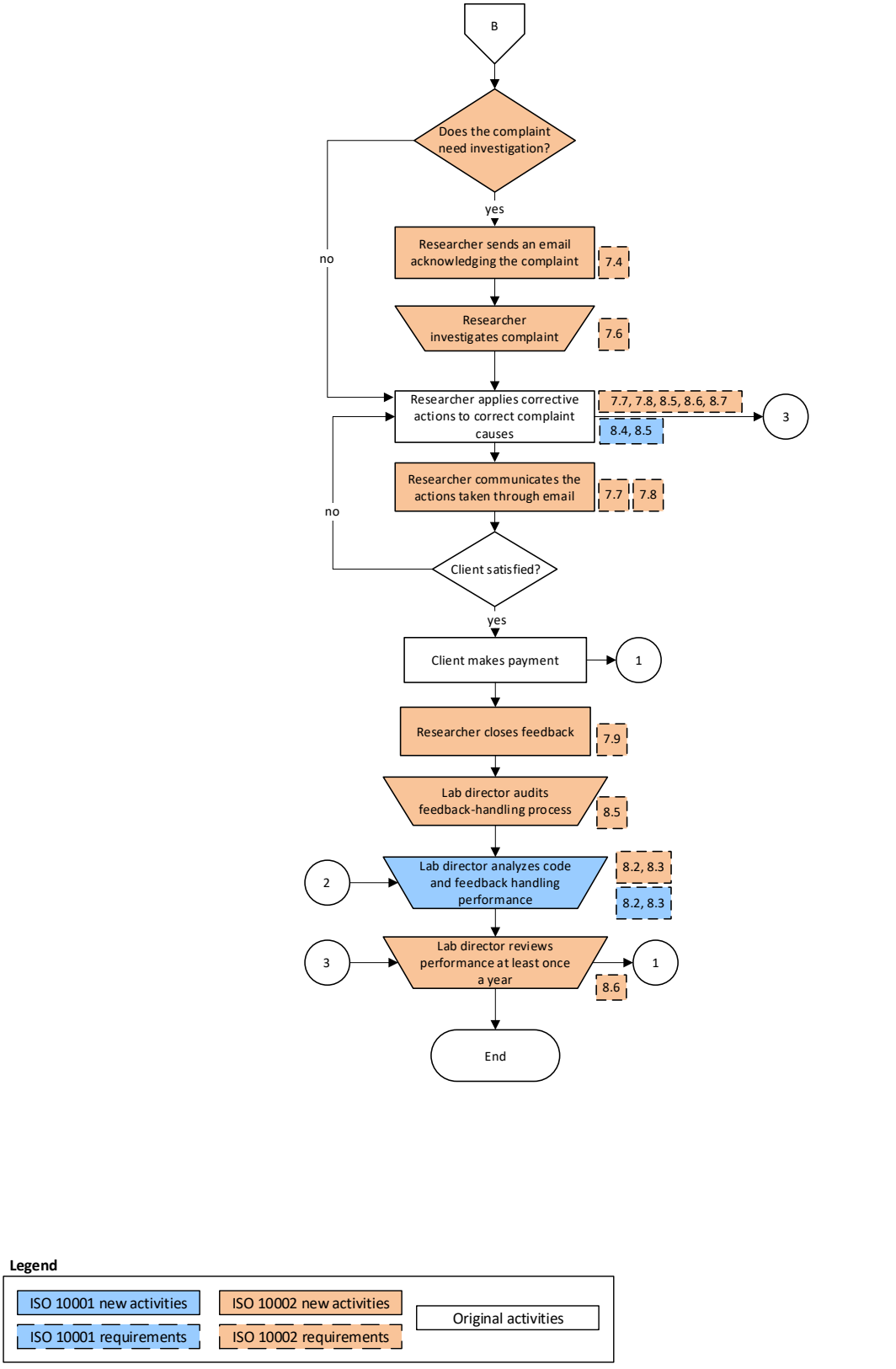
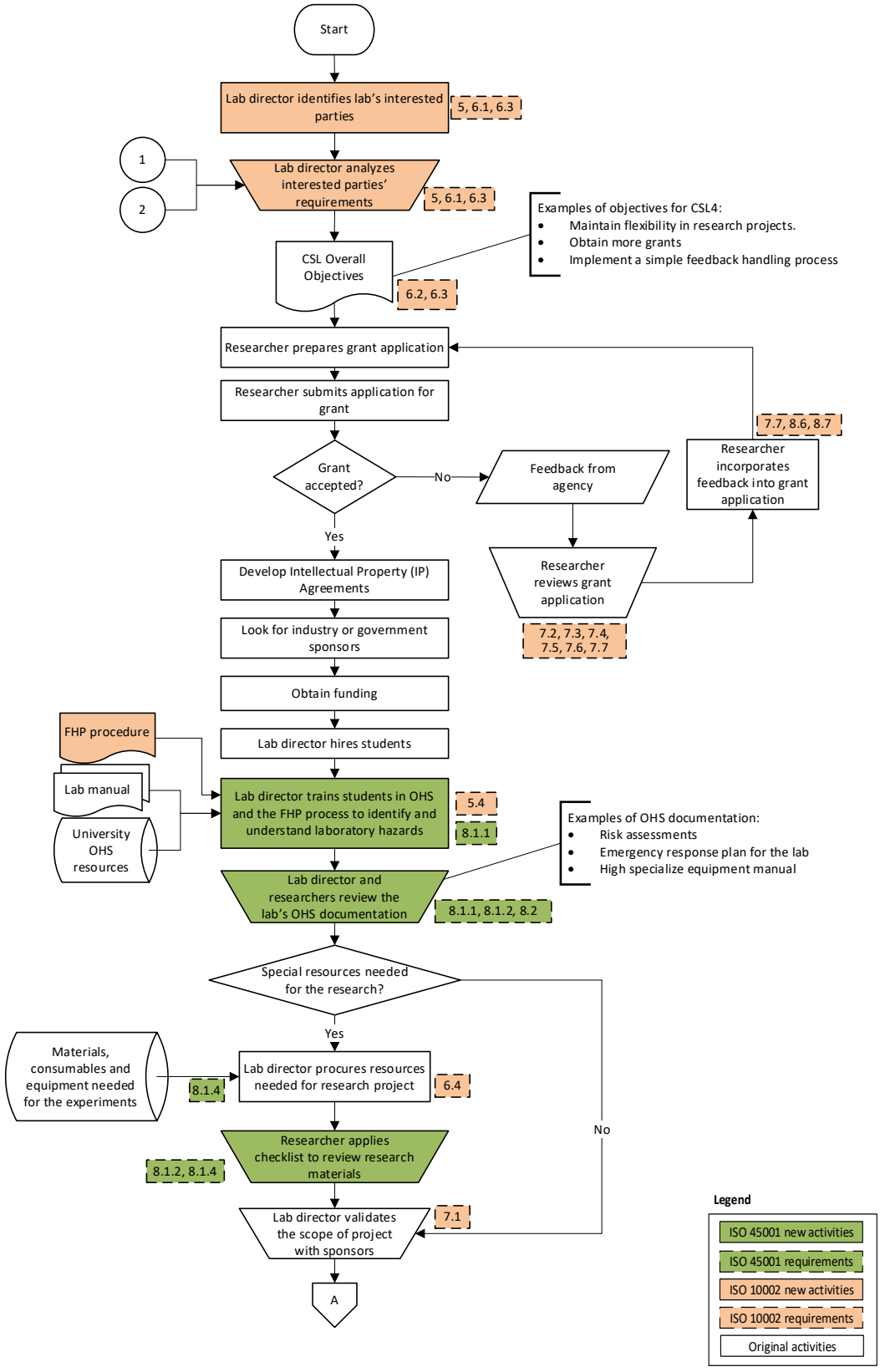


**Figure 6.3 (continued): CSL3 Integrated MS flowchart**



## Figure 6.4: CSL4 Integrated MS flowchart



## Figure 6.4 (continued): CSL4 Integrated MS flowchart

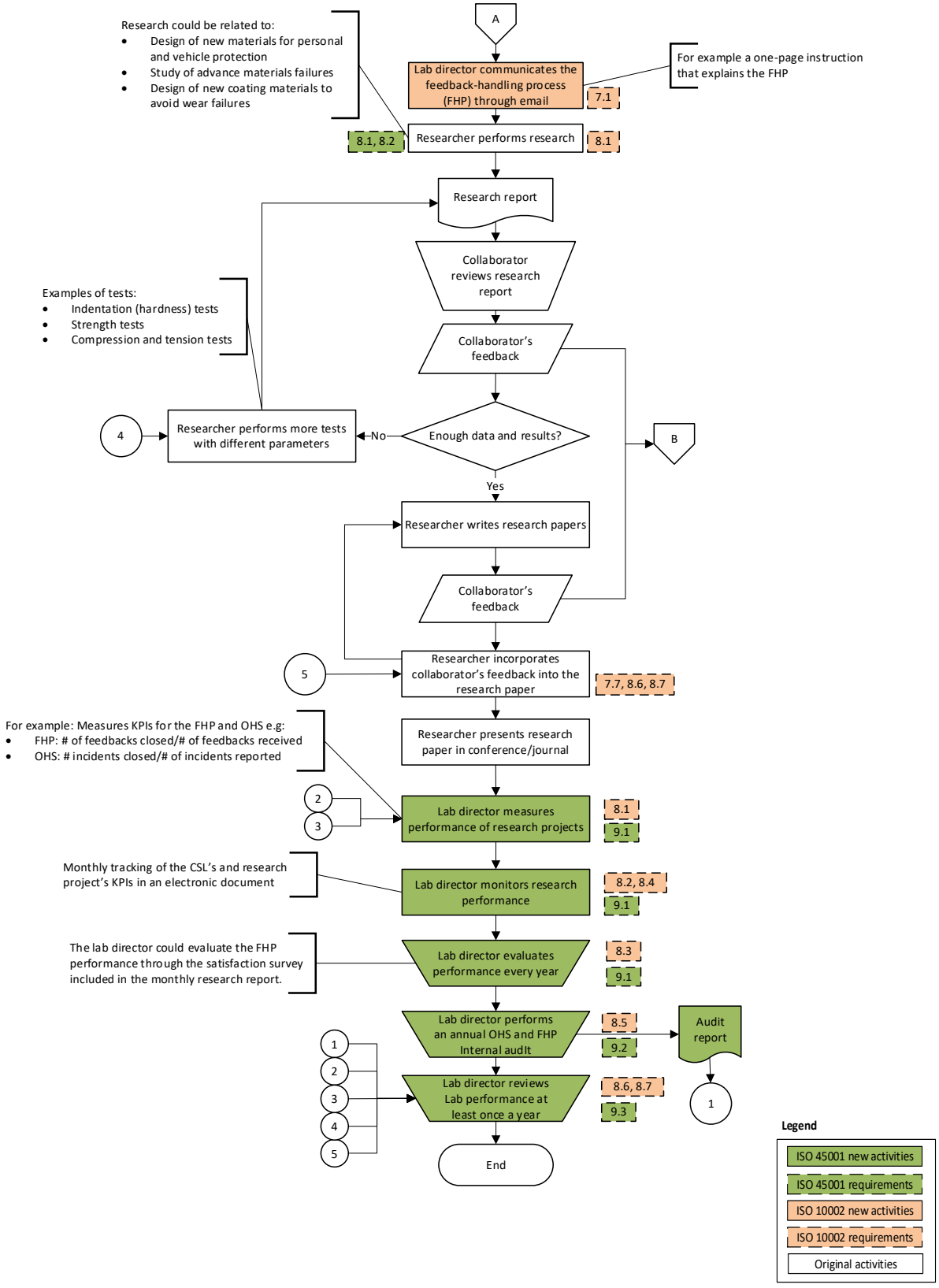
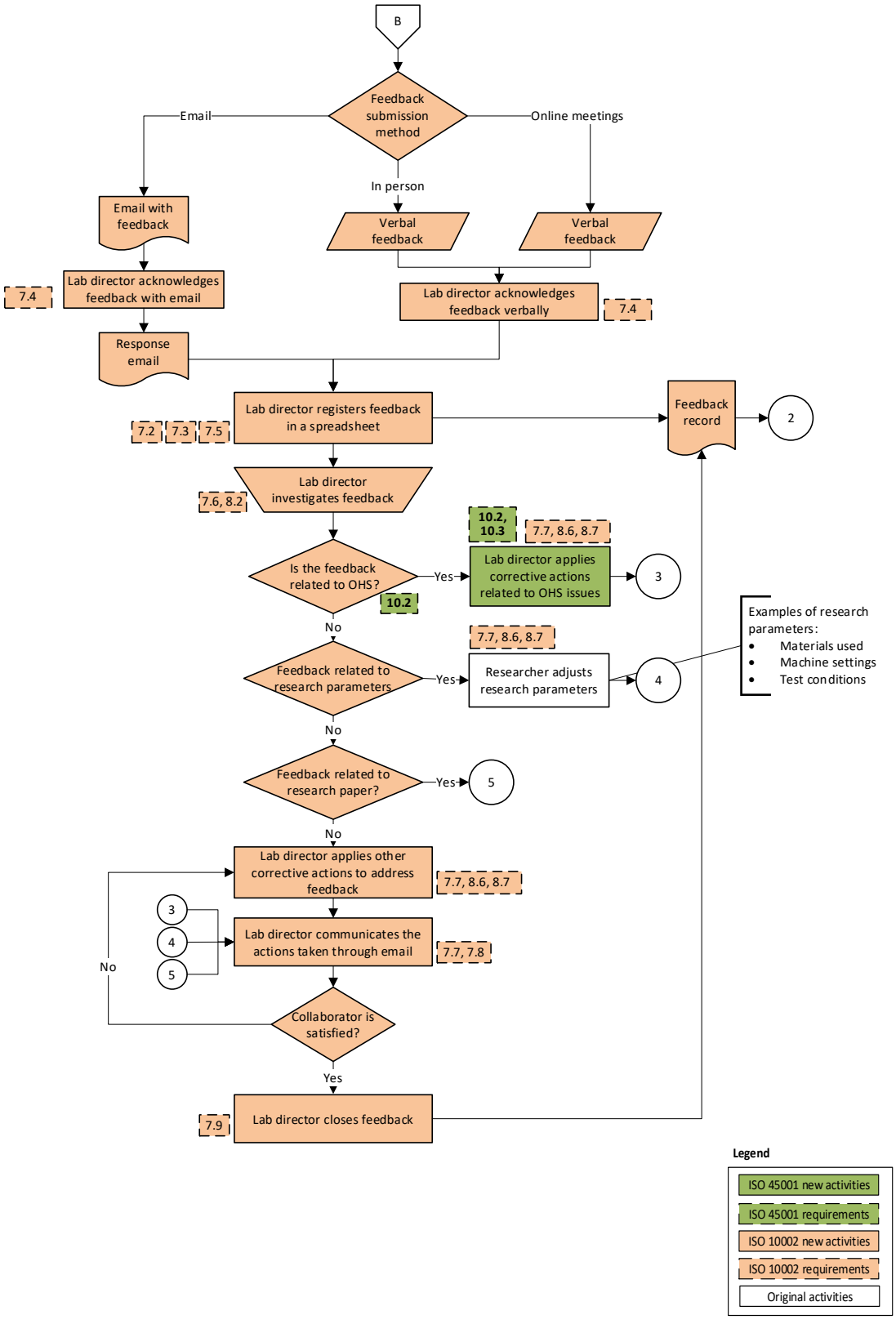


**Figure 6.4 (continued): CSL4 Integrated MS flowchart**



### 6.4.3 Verify gap closure

According to ISO (2018e), there are three types of gap closure in integration. The first one corresponds to the verification of the full implementation of the requirements of each standard. The second one involves the verification of the existence of a component that addresses the MSS requirement. The third one implicates the verification of the integration of the requirements into the MS.

#### 6.4.3.1 Desk audit for customer satisfaction code in CSL3

A desk audit was conducted to show an example of the first type of gap closure in integration. This desk audit involved the verification of the implementation of requirements in CSL3, specifically clause 6.4 of ISO 10001, "*Prepare code*." The purpose was to verify if the suggested code complies with the MSS requirement. The customer satisfaction code proposed in Table 6.2 states:

*"A research progress report should be sent to the customer within the first week of the upcoming month, or the laboratory director will provide an explanation and a progress presentation at the customer's facility. This code is valid for the entire duration of the research. The delivery cannot be guaranteed during holidays or in cases of natural or technical events outside of the control of the laboratory. Please inform the laboratory of any concern or feedback through the laboratory director email or phone".*

The following table presents an analysis of the fulfillment of requirements from ISO 10001 clause 6.4.

**Table 6.4: Verification of gap closure**

| ISO 10001 Clause 6.4 | Comments |
|---|---|
| *"… be clear, concise, accurate and not misleading, written in simple language."* | There was a grammatical mistake in the original code that could mislead the intention: the use of "should" instead of "will." |
| *the code's scope and purpose appropriate to the organization and its customers;* | Ok |
| *the promises made by the organization to its customers that can be fulfilled, and any limitations concerning those promises;* | Specify that the code is valid for the entire duration of the research project.<br>Specify the delivery of the progress report. |
| *definitions of key terms used in the code;* | A definition for "upcoming month" is missing.<br>"Upcoming month: The first month after the end of the month when the report is done." |
| *how and to whom enquiries and complaints about the code should be directed;* | The original sentence was not clear. |
| *a description of what action will be taken if the code promises are not fulfilled.* | OK |

Therefore, as a result of the gap closure verification, the corrective actions were applied, and the code was updated. The verified version of the code fully complies with the requirements of clause 6.4 ISO 10001.

The changes in the original version of the code are shown next. The removed parts are crossed out, and the added elements are underlined:

*"A research's progress report ~~should~~ will be sent to the customer within the first week of the upcoming month (the first month after the end of the month when the report is done), or the laboratory director will provide an explanation and a progress presentation at the customer's facility. This code is valid for the entire duration of the research project. The delivery of the progress report cannot be guaranteed during holidays or in cases of natural or technical events outside of the control of the laboratory. ~~Please inform the laboratory of any concern or feedback through the laboratory director email or phone~~. Please inform the laboratory director of any concern or feedback through email or phone."*

An "investigation" process established for both purposes: investigate feedback (as required in 7.6 of ISO 10002) and investigate incidents (required in 10.2 of ISO 45001) is an example of the verification of the integration of the requirements into CSL4 MSs (i.e., the second type of gap closure in integration). As the investigation requirement in ISO 45001 exceeds the one in ISO 10002, the CSL4 could match both with the ISO 45001 requirement.

#### 6.4.3.2 Maintenance and Improvement for ISO 10001 and ISO 10002 in CSL3

A satisfaction survey was developed to measure the satisfaction of laboratory customers with the customer satisfaction code and the feedback-handling process (Figure 6.6). The first question seeks to evaluate the code performance (ISO 10001, 8.2), the second client satisfaction with the code (ISO 10001, 8.3) and the third client satisfaction with the feedback-handling process (ISO 10002, 8.3). This satisfaction survey will be included in the Monthly Research Report.

**Figure 6.5: Survey to measure customer satisfaction with code and FHP**

1. I have received the Monthly Progress Research Report on time:
a) Yes
b) No

2. The Monthly Progress Research Report provides me with sufficient information about my research project:
a) Yes
b) No
If you choose "no," please specify what additional information should be included in this report:
_____

3. I am satisfied with the way the laboratory handles my feedback regarding the research project:
a) Yes
b) No
If you choose "no," please specify why not:

_____

#### 6.4.3.3 Responsibility, authority, and communication for ISO 10002 in CSL4

A feedback-handling flowchart (Figure 6.6) and a roles and responsibilities table (Table 6.5) were developed to train people in the laboratory on the activities and duties assigned for this process. The feedback-handling flowchart will also be included in the email sent to the clients to communicate this process.

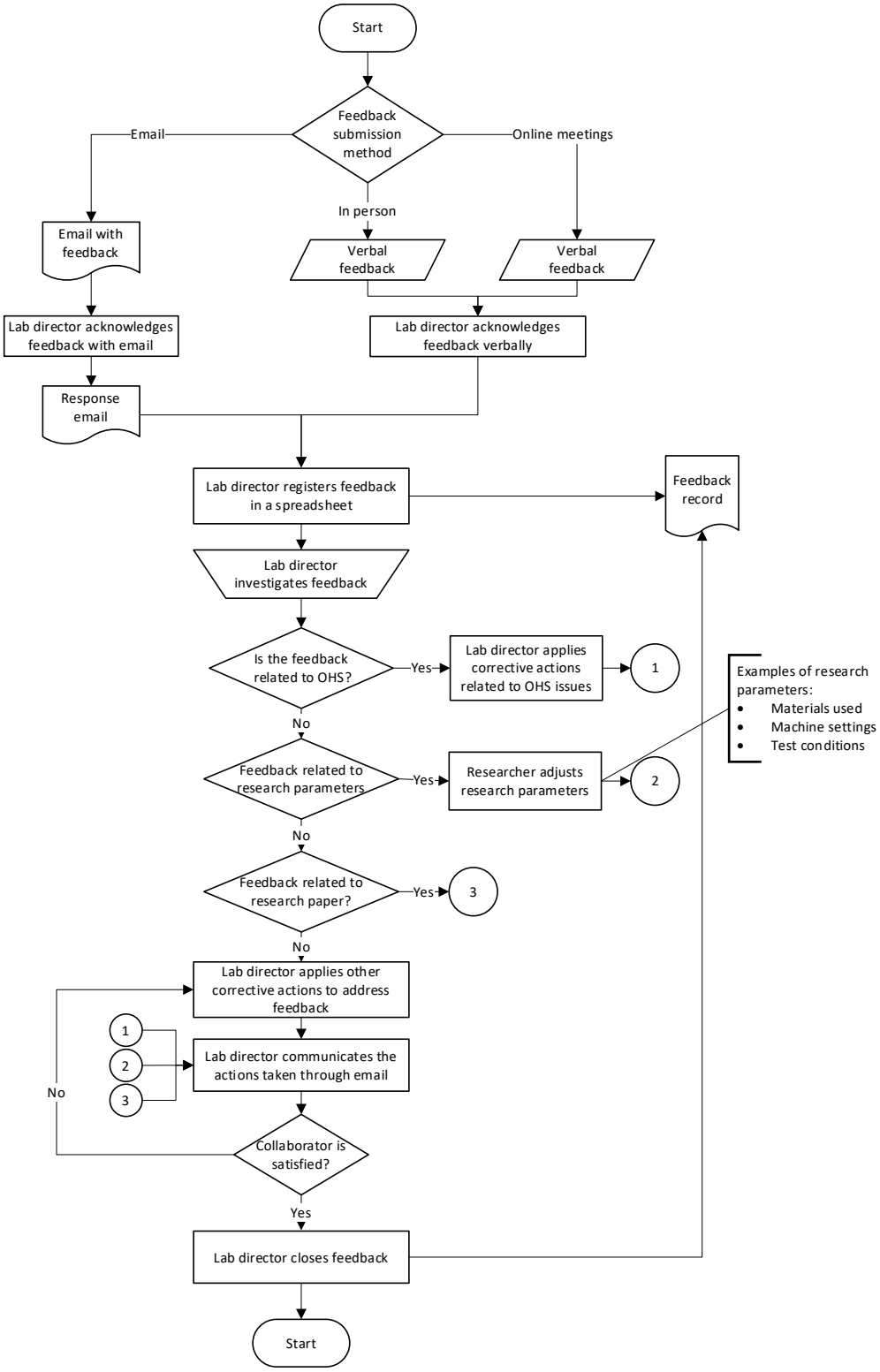
**Table 6.5: Roles and responsibilities for the feedback handling process**

| FHP Activities | Responsible | Method |
|---|---|---|
| Acknowledgement of feedback | R, D | Email, verbal |
| Register of feedback | D | Spreadsheet |
| Feedback investigation | D | "5-whys" Technique |
| Application of corrective actions related to OHS | D | Depending on the action |
| Application of corrective actions related to research or research paper | R | Written comments |
| Communication of corrective actions taken | D | Email |
| Closure of feedback | D | Spreadsheet |

R: Researcher

D: Laboratory director

**Figure 6.6: Feedback-handling process flowchart**



## 6.5 Summary

This chapter presented the applicability of the IUMSS methodology for the integration of the ISO 10001 and ISO 10002 requirements into the MS of CSL3 and the ISO 10002 and ISO 45001 requirements into the MS of CSL4, respectively.

Sub-chapter 6.2 discussed the leadership component, the integrated MS scope and a basic plan for the integration processes.

Sub-chapter 6.3 examined the connection between the MSSs requirements and the CSL's MSs. This process included structuring of the CSLs' MSs (6.3.1), structuring of the MSSs requirements (6.3.2), with three common and two specific requirements used, and mapping (6.3.3), where the juxtaposition approach was used to present the relationships between the requirements and the MSs elements.

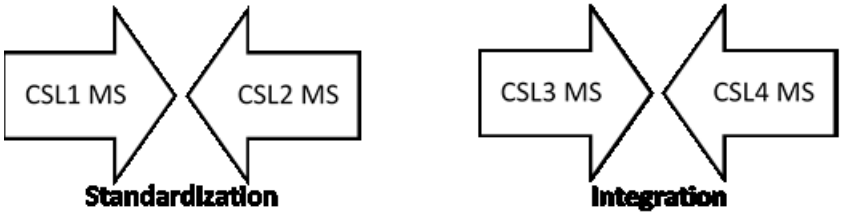
Sub-chapter 6.4 illustrated how the new MSS requirements could be integrated into the CSLs' current MSs, for example, by adding new processes or by modifying an MSs element like the CSLs' objectives. The aspects discussed in this sub-chapter included the gap identification and analysis (6.4.1). In addition, gap closure (6.4.2), where updated flowcharts show the inclusion of new processes to meet the requirements, like in CLS3, for which a process for developing and conducting a survey to assess satisfaction with the code and the feedback-handling process was added. Finally, gap closure verification (6.4.3) illustrated two types of gap closure in integration.

# 7 Comparisons of laboratories' MSs

Four types of comparisons among the CSLs MSs are shown in this chapter. The similarities and differences between the MSs elements (i.e., objectives, processes and resources) are examined for all these comparisons.

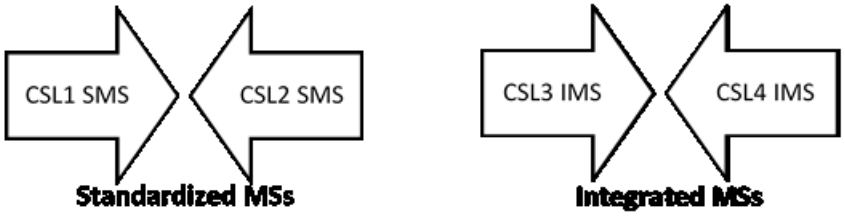
The first type of comparison is conducted between the original MSs that were in place before both standardization and integration processes (Figure 7.1). In other words, the comparison is performed between CSL1 and CSL2 (standardization) and CSL3 and CSL4 (integration).

**Figure 7.1: Input comparison**



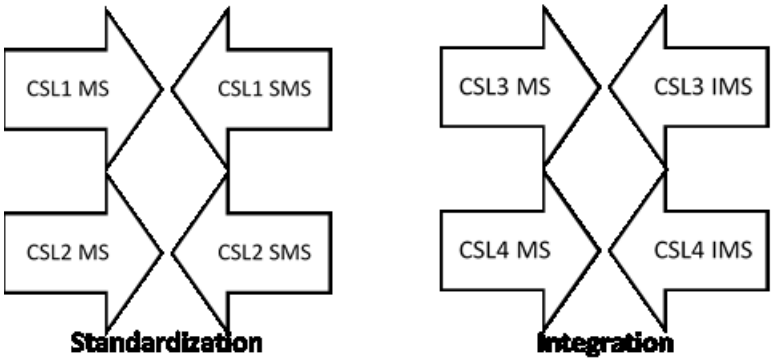

The second type of comparison is performed among the standardized management systems (SMSs) obtained after the standardization and integration processes (Figure 7.2). This comparison involves the same CSLs that were chosen for standardization and integration.

**Figure 7.2: Output comparison**



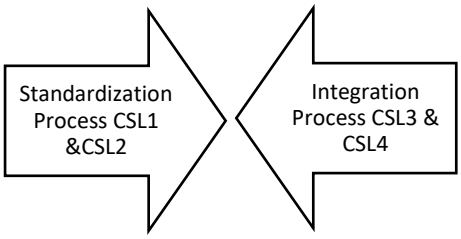

The third approach compares the original MSs and the resultant SMS or integrated management system (IMS) for each CSL (see Figure 7.3).

**Figure 7.3: Input versus Output Comparison**




Finally, the last comparison involves the processes followed to standardize and integrate a specific CSL MS (Figure 7.4). Thus, the IUMSS methodology used to standardize and integrate the CSLs MSs is compared in this last step.

**Figure 7.4: Process Comparison**




## 7.1 Comparison of the original MSs (Input)

The first type of comparison is performed among the original CSLs MSs, the input MSs. Thus, the comparison is conducted between the CSLs used to illustrate the standardization (CSL1 and CSL2) and the integration process (CSL3 and CSL4).

### 7.1.1 CSLs used for standardization

Table 7.1 shows the similarities and differences between the CSLs used in the standardization process. The first column presents the elements of the MSs against both CSLs are compared. These elements were developed in detail in Chapter Four.

**Table 7.1: Input Comparison**

| CSLs MSs Elements | Similarities | Differences |
|---|---|---|
| **Objectives** | | Each CSL has its objectives. |
| **Processes** | | • Nine value-added activities and three review activities were identified in **CSL1** (Figure 4.1).<br>• Eight value-added activities and three review activities were identified in **CSL2** (Figure 4.2). |
| **Resources** | Both CSLs receive funding from the European Union and the university. | |
| **People** | | **CSL1** has six dedicated researchers.<br>Fifteen people work in **CSL2**, including professors, graduate students and researchers. |
| **Materials** | The university covers the materials for experiments. | They are specific for each type of experiment. |
| **Equipment** | Most of the machines were acquired with funding from the European Union. | • CSL1 uses one big piece of equipment (Ion beam accelerator) for its research.<br>• CSL2 uses multiple pieces of equipment for each research purpose (machining, welding, measuring, modelling). |
| **Infrastructure** | | • In CSL1, the whole facility is devoted to one specific topic: Ion beam technology and plasma.<br>• CSL2 also has an ample facility, but it serves various research associated with machines in the industry. |
| **Organizational structure** | Both CSLs belong to a university located in a central European country. | • CSL1 has one director for the research facility.<br>• CSL2 has four coordinators, each of them in charge of a group of research. |
| **Products/Services** | Both have research reports as a deliverable. | • CSL1 expects to mainly provide services to the local industries as a long-term goal.<br>• CSL1 focused on ion beam technology, plasma deposition and modification, and ion beam analysis.<br>• CSL2 currently provides services to the local industries.<br>• CSL2 focuses on developing pieces based on reverse engineering and usually has a prototype as a deliverable. |
| **Customers** | The external clients of both CSLs are private industries and other universities that are interested in their research topics. | Internal clients are different:<br>• CSL1 only has Ph.D. students and post-doctoral fellows.<br>• CSL2 has undergraduates (as part of some academic courses), graduate students and post-doctoral fellows. |
| **Stakeholders** | Both CSLs have similar stakeholders: the Dean of the laboratory's faculty, the teaching and technical community, grant agencies, the academic community, students and society. | |

A relevant aspect presented in Table 7.1 in terms of similarities is that as both CSLs belong to the same university, both have analogous university governance and, therefore, some shared processes external to the CSLs, like resources acquisition (materials, equipment). A common deliverable of both CSLs is the research reports sent from CSLs research teams to customers.

Customers (e.g., private industries) and stakeholders (e.g., Dean of the laboratory's faculty, the teaching and technical community, grant agencies, the academic community, students and the society) are also similar. Finally, both CSLs have large facilities with massive specialized equipment.

Among the main differences are the internal processes of each CSL. CSL2 has more complexity in terms of processes. This complexity is associated with more activities, workers, specialized machines, and equipment devoted to different research topics. Therefore, unique research coordinators are needed. CSL1, on the other hand, focuses just on one research topic and therefore has a simpler management system.

### 7.1.2 CSLs used for integration

Similar to the previous section, the following table compares the initial MSs from CSL3 and CSL4.

**Table 7.2: Input Comparison**

| Input MSs CSL3 vs CSL4 | | |
|---|---|---|
| **CSLs MSs Elements** | **Similarities** | **Differences** |
| **Objectives** | | Each CSL has its objectives:<br>• One of CSL3's main objectives is to obtain more funding to renovate equipment. Another objective is to attract more graduate students.<br>• For CSL4, one objective is to participate in conferences and publish research papers continually. |
| **Processes** | Both CSLs have simple processes with few activities. | • Eight value-added activities and two review activities were identified in CSL3 (Figure 4.3).<br>• Fourteen value-added activities and three review activities were identified in CSL4 (Figure 4.4). |
| **Resources** | Both CSLs use university budget for daily operations | • CSL3 receives funding from European Union.<br>• CSL4 receives funding from North American private institutions. |
| **People** | | • CSL3 has six persons working there, including professors, assistant professors, graduate students and researchers.<br>• CSL4 is run by one professor who manages all the research projects. |
| **Materials** | The university covers the materials for experiments. | |
| **Equipment** | | • CSL3 has some out-of-date equipment and also some unique patented equipment.<br>• CSL4 has high technology specialized equipment like high-speed cameras. |

**Table 7.2 (continued): Input Comparison**

| CSLs MSs Elements | Similarities | Differences |
|---|---|---|
| **Infrastructure** | Both CSLs have two dedicated spaces for different topics of research and are relatively small spaces. | |
| **Organizational structure** | Both CSLs belong to a Mechanical Engineering department. | • CSL3 is located in the capital city of a European country.<br>• CSL4 is located in a Canadian city. |
| **Products/Services** | Both CSLs have research reports and research papers as deliverables. | • CSL3 specializes in particles and powder materials and heat and mass transfer.<br>• Typical outputs of CSL3's are prototypes of specific equipment, new methods of processing particles and powder materials, drawings, strength calculations.<br>• CSL4 focuses on materials science and does research related to defence materials for military and aerospace-industry purposes. Research topics are of long-term duration (from four to six years). |
| **Customers** | Internal clients are similar:<br>They include undergraduate and graduate students and people from other laboratories on campus that ask for expert opinions and conduct experiments on specific topics and collaborative research. | External clients are different:<br>• CSL3 works with chemical, pharmaceutical, fertilizer and textile industries.<br>• For CSL4, the external clients are the collaborators or people who give them funding for the research. |
| **Stakeholders** | Similar stakeholders: Dean of the laboratory's faculty, the teaching and technical community, grant agencies, the academic community, students and society. | Collaborators are an essential stakeholder for the **CSL4.** |

Table 7.2 shows significantly more differences than similarities between the CSLs. Since these CSLs conduct research related to different topics, their external customers pertain to other industries. A group of people work in CSL3, including professors, assistant professors, graduate students and researchers, while only one professor runs CSL4. Therefore, the decision-making for the integration process might be easier for CSL4.

CSL3 and CSL4 also differ in the technological level of their equipment. Concerning their stakeholders, CSL4 considers the collaborators of the research projects (e.g., companies requesting the research project) as the main stakeholder, whereas CSL3 does not have that collaborator role.

Both CSLs belong to the Mechanical Engineering departments, and their daily operations and required materials for experimentation are funded by their respective university. Undergraduate and graduate students are the internal clients of both CSLs.

## 7.2 Comparison of the resultant MSs (Output)

### 7.2.1 Standardized MSs

The comparison presented in this section is performed between two MSs standardized with two assimilative MSSs, ISO 45001 and ISO 9001, for the CSL1 and CSL2, respectively. The MSs resulting from the standardization processes depicted in the flowcharts in section 5.4.2 (Figures 5.1 and 5.2) are compared in this section.

As was indicated in section 5.2, only five clauses (two specific clauses and three common ones) were selected as an example to show the standardization processes. Therefore, the analysis presented in this section may be more complex for the application of the full MSSs. However, it will serve as an illustration of the application of the standardization processes.

The first point that can be observed when comparing the flowcharts resulting from the standardization processes is that the main changes in the CSLs' MSs are related to activities and processes, not much in terms of objectives and resources. This is because only minor adjustments to fit the MSSs requirements are needed for both objectives and resources. For example, the overall CSL1's objectives would need to include OH&S aspects, like reducing the high radiation levels at the ion beam facility. To fulfill this objective, the CSL1 would need to acquire and deploy the necessary resources, such as installing fixed high radiation detectors in various points of the CSL1 and installing the technology required to monitor radiation levels in real-time inside this laboratory. Another example of a change related to resources can be seen in clause 8.1.4 for the procurement of resources. The implementation of a checklist to verify that materials, supplies and goods are in good condition before their use in research experiments is an example of a resource needed to fulfill clause 8.1.4.

In terms of the activities, some of them were either added or changed to fulfill the MSSs requirements. The main changes in the activities are discussed next.

For the CSL1, in Figure 5.1, two product/service realization activities comply fully with ISO 45001 clauses. The first activity is "*clients visit lab to see equipment*," which complies with clauses 8.1.1 and 9.1.1. As part of this activity, people who visit the CSL1 are issued a device that measures their radiation levels. This device alerts if the person is exposed to any level of radiation. This activity is an example of the implementation of an operational control, radiation detector (ISO

45001, 8.1.1) and an example of monitoring and measurement of performance in regards to the extent to which a safety requirement is fulfilled (ISO 45001, 9.1.1.a).

The second product/service realization activity is "*schedule the experiments*," which complies with clauses 8.1.1, 8.1.2 and 8.2. Work procedures and instructions for this activity indicate how to perform research in the CSL1. These documents are an example of an operation control (ISO 45001, 8.1.1, 8.1.2.d). An emergency response plan is also in place (ISO 45001, 8.2) that covers multiple situations during the research activities, such as an overcharge or malfunction of the ion beam accelerator.

Thirteen new activities were added to the system. Eight of them are managerial activities, and five are review/managerial activities. One of the managerial activities, "*Establish controls to eliminate hazards and reduce risks*," was added to fulfill multiple ISO 45001 MSS requirements (i.e., sub-clauses 8.1.2, 8.1.3, 8.1.4 and 8.2). In the case of sub-clause 8.1.2, since it was partially fulfilled with the previous activity, two activities, "*identify hazards associated with the research project"* and *"assess risks associated with the hazards of the research project,"* were needed to cover its requirements fully.

Two review/managerial activities were added to address a single ISO 45001 MSS' sub-clause: "*lab director performs an internal OHS audit every six months*" and "*lab director reviews performance at least once a year*," which meet clauses 9.2 and 9.3, respectively.

There are also cases where more than one activity was included to fulfill a single clause or sub-clause. For example, three managerial activities ("*define the scope of the OH&S MS*," "*identify hazards of the laboratory,*" and "*assess OH&S risks of the laboratory*") and two review/managerial activities ("*evaluate laboratory context*" and "*identify needs and expectations of interested parties*") were needed to satisfy sub-clause 8.1.1.

Similarly, for clause 9.1, two managerial activities ("*the lab director measures performance of research projects" and "the lab director monitors research OH&S performance)"* and a review/managerial activity (*"lab director evaluates OH&S performance")* were required.

Table 7.3 summarizes the activities of the CSL1's MS resulting from the standardization based on ISO 45001. Current activities refer to the activities included in the initial CSL1's MS (before standardization). Added activities refer to the ones incorporated into the resultant CSL1's MS (after standardization).

**Table 7.3: CSL1 Output ISO 45001 MS – current and added activities**

| | CSL1 Output ISO 45001 MS- Current and added activities | | | | |
|---|---|---|---|---|---|
| | **Clauses** | **# of activities** | **Activity Type** | **Activities description** | **Comments** |
| **Current activities** | 9.1 | 1 | Review | - Researcher reviews research results with the client. | A current activity addresses a MSS requirement. |
| | 8.1.1, 9.1.1 | 1 | Product/Service Realization | - Clients visit lab to see equipment. | Two current activities address multiple MSS requirements. |
| | 8.1.1, 8.1.2, 8.2 | 1 | Product/Service Realization | - Schedule the experiments. | |
| | **Total** | **3** | **current activities in total are addressing MSS requirements.** | | |
| **New activities added** | 8.1.2, 8.1.3, 8.1.4, 8.2 | 1 | Managerial | - Establish controls to eliminate hazards and reduce risks. | One activity to address multiple MSS requirements. |
| | 8.1.1 | 5 | Managerial | - Define the scope of the OH&S MS. | Three clauses, each of them addressed by multiple activities. |
| | | | Managerial | - Identify hazards of the laboratory. | |
| | | | Managerial | - Assess OH&S risks of the laboratory. | |
| | | | Review/ Managerial | - Evaluate laboratory context. | |
| | | | Review/ Managerial | - Identify the needs and expectations of interested parties. | |
| | 9.1 | 3 | Managerial | - Lab director measures the performance of the research project. | |
| | | | Managerial | - Lab director monitors research OH&S performance. | |
| | | | Review/ Managerial | - Lab director evaluates OH&S performance. | |
| | 8.1.2 | 2 | Managerial | - Identify hazards associated with the research project. | |
| | | | Managerial | - Assess risks associated with the hazards of the research project. | |
| | 9.2 | 1 | Review/ Managerial | - Lab director performs an internal OH&S audit every six months. | Two clauses, each of them addressed by a single activity. |
| | 9.3 | 1 | Review/ Managerial | - Lab director reviews performance at least once a year. | |
| | **Total** | **13** | **new activities in total needed to fulfill the MSS requirements.** | | |

In the CSL2, Figure 5.2, three activities and two feedback loops currently fully comply with the ISO 9001 clauses and do not need changes or adjustments. The first product/service realization activity is "*clients contact lab experts,*" which fully complies with clauses 8.2.1 and 8.2.2. The second product/service realization activity is *"clients explain the research requirements to lab director,"* which complies with clauses 8.2.1 and 8.3.3. The third is a review activity, *"lab director analyzes client's requirements,"* which complies with clauses 8.2.3, 8.2.4, 8.3.3 and 8.3.4. The feedback regarding the research project's feasibility shared by CSL2 with the client and the feedback provided by the client regarding the Research Proposal fulfill clause 8.2.1.

Regarding the new activities added, ten activities were needed to fulfill ISO 9001 MS requirements. Two product/service realization activities that meet multiple requirements were added: "*plan research steps,*" which accomplishes clauses 8.3.1 and 8.3.2, and "*researcher approves changes*" (clauses 8.2.1, 8.2.4 and 8.3.6).

There was a case where multiple activities were added to fulfill a single clause or sub-clause: clause 9.1 demanded the addition of four new activities. Two of them are managerial activities: "*lab director establishes quality KPIs for both the research project and the CSL2*" and "*lab director monitors performance bi-monthly*." The other two are review/managerial activities: "*lab director analyzes performance*" and "*lab director evaluates research performance*."

Finally, four new activities addressed a single ISO 9001 MSS' clause or sub-clause. These include two new review/managerial activities: "*lab director establishes internal audits between researchers every term*" and "*lab director reviews performance at least once a year,*" meeting clauses 9.2 and 9.3, respectively. The two other activities include a review activity: *"researcher analyzes required changes"* (clause 8.2.4) and a product/service realization activity: *"researcher creates a Specification Sheet"* (clause 8.3.5).

Table 7.4 summarizes the activities of the CSL2's MS resulting from the standardization based on ISO 9001. Current activities refer to the activities included in the initial CSL2's MS (before the standardization). Added activities refer to the ones incorporated into the resultant CSL2's MS (after the standardization).

**Table 7.4: CSL2 Output ISO 9001 MS - current and added activities**

| | **CSL2 Output ISO 9001 MS-Current and added activities** | | | | |
|---|---|---|---|---|---|
| | **Clauses** | **# of activities** | **Activity Type** | **Activities description** | **Comments** |
| **Current activities** | 8.2.1, 8.2.2 | 1 | Product/Service Realization | - Clients contact lab experts. | Three current activities address multiple MSS requirements. |
| | 8.2.1, 8.3.3 | 1 | Product/Service Realization | - Clients explain research requirements to the lab director. | |
| | 8.2.3, 8.2.4, 8.3.3, 8.3.4 | 1 | Review | - Lab director analyzes client's requirements. | |
| | 8.3.5 | 2 | Product/Service Realization | - Researcher performs machining of parts or prototype. | Two current activities address a single MSS requirement. |
| | | | Review | - Researcher inspects parts or prototypes. | |
| | **Total** | **5** | **current activities in total are addressing multiple MSS requirements.** | | |

**Table 7.4 (continued): CSL2 Output ISO 9001 MS - current and added activities**

| | Clauses | # of activities | Activity Type | Activities description | Comments |
|---|---|---|---|---|---|
| New activities added | 8.3.1, 8.3.2 | 1 | Product/Service Realization | - Plan research steps. | Two activities, each of them addresses multiple MSS requirements. |
| | 8.2.1, 8.2.4, 8.3.6 | 1 | Product/Service Realization | - Researcher approves changes. | |
| | 9.1 | 4 | Managerial | - Lab director establishes quality KPIs for both the research project and the CSL2. | Multiple activities address one clause. |
| | | | Managerial | - Lab director monitors performance bi-monthly. | |
| | | | Review/ Managerial | - Lab director analyzes performance. | |
| | | | Review/ Managerial | - Lab director evaluates research performance. | |
| | 9.2 | 1 | Review/ Managerial | - Lab director establishes internal audits between researchers every term. | Four clauses, each of them addressed by a single activity. |
| | 9.3 | 1 | Review/ Managerial | - Lab director reviews performance at least once a year. | |
| | 8.2.4 | 1 | Review | - Researcher analyzes required changes. | |
| | 8.3.5 | 1 | Product/Service Realization | - Researcher creates a Specification Sheet. | |
| | **Total** | **10** | **new activities in total needed to fulfill the MSS requirements.** | | |

After analyzing the MSs that resulted from the standardization processes in both CSLs in terms of the new activities added and comparing the shared and specific clauses from each MSS, it can be observed that only one added activity addresses multiple ISO 45001 clauses in CSL1. In contrast, in CSL2, two added activities address multiple ISO 9001 clauses. In both CSLs, these are clauses specific to each standard: 8.1 and 8.2 for CSL1 and 8.2 and 8.3 for CSL2.

Both resulting MSs have clauses addressed by multiple activities. In CSL1, a specific clause (8.1.1) is addressed by five activities. A clause addressed by various activities in both CSLs is a common clause (9.1), needing four activities in both cases.

Table 7.5 shows the output comparison between CSL1 and CSL2 in terms of activities (activities that were not modified and new activities added to fulfill the MSSs requirements) and the number of clauses addressed by those activities.

**Table 7.5: Output comparison CSL1 versus CSL2**

| Types of activities | | CSL1 ISO 45001 | CSL2 ISO 9001 |
|---|---|---|---|
| **Current activities** | # of activities that address multiple MSS clauses | • One activity addresses one clause.<br>• One activity addresses two clauses.<br>• One activity addresses three clauses. | • One activity addresses four clauses.<br>• Two activities address one clause.<br>• Two activities address two clauses each. |
| **New activities added** | # of activities that address multiple MSS clauses | One activity addresses four clauses. | • One activity addresses two clauses.<br>• One activity addresses three clauses. |
| | # of individual clauses addressed by multiple activities | • One clause is addressed by five activities.<br>• One clause is addressed by three activities.<br>• One clause is addressed by two activities. | One clause is addressed by four activities. |
| | # of individual clauses addressed by a single activity | Two clauses are addressed by a single activity. | Four clauses are addressed by a single activity. |

### 7.2.2 Integrated MSs

The MSs that resulted from the integration processes depicted in section 6.4.2 were used for this comparison. For CSL3, the integration involved MSs based on augmentative MSSs (ISO 10001 and ISO 10002). For CSL4, the integration was between an MS based on an assimilative MSS (ISO 45001) and an MS based on an augmentative MSS (ISO 10002).

Similar to the previous section, the comparison included the activities added or changed to fulfill the requirements from the MSSs for the integration processes. The main changes in the activities are shown next.

For CLS3, integration with ISO 10001 and ISO 10002 (Figure 6.3), five current activities comply with the MSSs requirements. Three product/service realization activities address multiple clauses in both MSs: "*clients interested in research on powder and particulate materials contact lab experts*," "*lab team prepare a Research Proposal," and "researcher performs research*." The other two activities are a review activity, "*client reviews monthly research results,"* and a managerial activity, *"the researcher applies corrective actions to correct complaint causes.*" These two activities address various clauses in both MSs.

The current elements of the CSL3 MS (Objectives, processes and resources) would need some changes to address the MSSs requirements fully. For example, the objectives would need to be modified to complete the MSSs requirements for ISO 10001 and ISO 10002 by obtaining and analyzing critical information from relevant interested parties (potential students, industry community, and department authorities) to set the objectives in terms of the code and the feedback handling process.

Concerning ISO 10002, six activities were added, all of them addressing a single clause. Two other activities were added to meet two ISO 10002 MSS requirements.

With regards to ISO 10001, three new activities were added. Among them, one activity (*"lab director develops a customer satisfaction code"*) addresses a single ISO 10001 MSS' sub-clause (6.4). There are also two activities ("*lab director and researcher review code*" and *"researcher sends the Monthly Research Report to the client via email"*) that address two ISO 10001 clauses (6.4 and 8.4, and 7 and 8.1, respectively).

The remaining six activities address multiple clauses in both MSSs (ISO 10001 & ISO 10002), meeting at least one clause from each MSSs.

Table 7.6 summarizes the activities of the CSL3's MS resulting from the integration based on ISO 10001 and ISO 10002. Current activities refer to the activities included in the initial CSL3's MS (before integration). Added activities refer to those incorporated into the resultant CSL3's MS (after integration).

**Table 7.6: CSL3 Output ISO 10001 & ISO 10002 MS – current and added activities**

| | CSL3 Output ISO 10001 & ISO 10002 MS- Current and added activities | | | | | |
|---|---|---|---|---|---|---|
| | Clauses | | # of activities | Activity Type | Activities description | Comments |
| | ISO 10001 | ISO 10002 | | | | |
| Current activities | 6.2, 6.3 | 6.3 | 1 | Product/Service Realization | - Clients interested in research on powder & particulate materials contact lab experts. | Five current activities address multiple MSS requirements in both MSSs. |
| | 8.1 | 8.1 | 1 | Product/Service Realization | - The researcher performs research. | |
| | 8.4, 8.5 | 7.7, 7.8, 8.5, 8.6, 8.7 | 1 | Managerial | - The researcher applies corrective actions to correct complaint causes. | |
| | 6.4, 7 | 7.1 | 1 | Product/Service Realization | - The lab team prepare a Research Proposal. | |
| | 8.2, 8.3, 8.4 | 8.2, 8.3, 8.4 | 1 | Review | - Client reviews monthly research results. | |
| | **Total** | | **5** | **current activities in total addressing MSSs requirements.** | | |
| New activities added | 6.4 | - | 1 | Managerial | - Lab director develops customer satisfaction code. | One activity addresses a single ISO 10001 MSS requirement. |
| | 6.4, 8.4 | - | 1 | Review/ Managerial | - The lab director and researcher review the code. | Two activities address multiple ISO 10001 MSS requirements. |
| | 7, 8.1 | - | 1 | Product/Service Realization | - The researcher sends the Monthly Research Report to the client via email. | |

**Table 7.6 (continued): CSL3 Output ISO 10001 & ISO 10002 MS – current and added activities**

| | Clauses | | # of activities | Activity Type | Activities description | Comments |
|---|---|---|---|---|---|---|
| | ISO 10001 | ISO 10002 | | | | |
| New activities added | - | 7.5 | 1 | Review | - The researcher assesses feedback. | Six activities, each one addresses a single ISO 10002 MSS requirement. |
| | - | 7.4 | 1 | Managerial | - The researcher sends an email acknowledging the complaint. | |
| | - | 7.6 | 1 | Review/ Managerial | - The researcher investigates the complaint. | |
| | - | 7.9 | 1 | Managerial | - The researcher closes feedback. | |
| | - | 8.5 | 1 | Review/ Managerial | - The lab director audits the feedback-handling process. | |
| | - | 8.6 | 1 | Review/ Managerial | - The lab director reviews performance at least once a year. | |
| | - | 7.7, 7.8 | 1 | Managerial | - The researcher communicates the actions taken through email. | One activity addresses two ISO 10002 MSS requirements. |
| | 5, 6.1 | 5, 6.1 | 1 | Managerial | - The lab director identifies the lab's interested parties. | Seven activities address multiple MSS requirements in both MSs. |
| | 5, 6.1 | 5, 6.1 | 1 | Review/ Managerial | - The lab director analyzes interested parties' requirements. | |
| | 6.5, 6.6, 6.7, 6.8, 7 | 6 | 1 | Managerial | - The lab director prepares code supporting processes. | |
| | 6.8, 7 | 7.1 | 1 | Managerial | - The lab director communicates the FHP and the customer satisfaction code to the clients through email. | |
| | - | 7.3, 8.1 | 1 | Managerial | - The researcher registers the feedback in a spreadsheet. | |
| | 7, 8.1 | 8.1, 8.4 | 1 | Product/Service Realization | - The researcher prepares Monthly Research Report. | |
| | 8.2, 8.3 | 8.2, 8.3 | 1 | Review/ Managerial | - The lab director analyzes code and FHP. | |
| | **Total** | | **17** | **new activities in total needed to fulfill the MSS requirements.** | | |

For the CSL4, which exemplifies the integration of MSs based on ISO 10002 and ISO 45001 (Figure 6.4), the objectives of the resulting integrated MS would need to include the FHP objectives to fulfill with clauses 6.2 & 6.3 of ISO 10002. Although no clauses from ISO 45001 related to objectives were selected for integration, OH&S objectives need to be defined to guide the integration process.

Regarding ISO 10002, five current activities needed to be modified to comply with the requirements fully. Among them, one addresses a single clause: "*lab director validates the scope of the project with sponsors*" (7.1). The other four activities address multiple clauses such as *"researcher reviews grant application"* (7.2, 7.3, 7.4, 7.5, 7.6, 7.7), *"researcher incorporates feedback into the grant application"* (7.7, 8.6, 8.7), *"researcher incorporates collaborator's*

*feedback into the research paper"* (7.7, 8.6, 8.7), and *"researcher adjusts research parameters"* (7.7, 8.6, 8.7).

In addition, ten new activities were added to the MS to fulfill ISO 10002 requirements. Four activities address a single clause ("*lab director communicates the feedback-handling process through email*" 7.1, *"lab director closes the feedback"* 7.9, *"lab director acknowledges feedback with email"* 7.4, *"lab director acknowledges feedback verbally"* 7.4). Six activities fulfill multiple ISO 10002 clauses (*"lab director identifies the lab's interested parties"* 5, 6.1, 6.3, *"lab director analyzes interested parties' requirements*" 5, 6.1, 6.3, *"lab director registers feedback in a spreadsheet"* 7.2, 7.3, 7.5, *"lab director applies corrective actions to address feedback"* 7.7, 8.6, 8.7, *"lab director investigates feedback"* 7.6, 8.2, *"lab director communicates actions taken through email,"* 7.7, 7.8).

Regarding ISO 45001, nine new activities were added. Two of these activities address multiple clauses of the ISO 45001-based OH&SMS: *"the lab director and researchers review the lab's OH&S documentation"* (8.1.1, 8.1.2, 8.2), and *"the researcher applies a checklist to review research materials"* (8.1.2, 8.1.4). The other seven activities address multiple clauses in both MSSs (i.e., ISO 10002 and ISO 45001): *"lab director trains students in OH&S and FHP to identify and understand laboratory hazards," "lab director measures the performance of research projects*," "*lab director monitors research performance*," *"lab director applies corrective actions related to OH&S issues,"* "*lab director evaluates performance every year," "lab director performs an annual OH&S and FHP internal audit*" and "*lab director reviews performance at least once a year*."

Two current product/service realization activities fulfill multiple clauses in both MSSs. Those activities are: "*the lab director procures resources needed for the research project*" and "*researcher performs research*."

Table 7.7 summarizes the current and added activities in the original MS flowchart in the CSL4 output flowchart MS based on ISO 45001 and ISO 10002.

## Table 7.7: CSL4 Output ISO 45001 & ISO 10002 MS - current and added activities

| | CSL4 Output ISO 45001 & ISO 10002 MS- Current and added activities | | | | | |
|---|---|---|---|---|---|---|
| | Clauses | | # of activities | Activity Type | Activities description | Comments |
| | ISO 45001 | ISO 10002 | | | | |
| Current activities | - | 7.1 | 1 | Review | - The lab director validates the scope of the project with sponsors. | One activity addresses a single ISO 10002 MSS requirement. |
| | | | | Review | | |
| | - | 7.2, 7.3, 7.4, 7.5, 7.6, 7.7 | 1 | Review | - Researcher reviews grant application. | Four activities address multiple ISO 10002 MSS requirements. |
| | - | 7.7, 8.6, 8.7 | 1 | Product/Service Realization | - The researcher incorporates feedback into the grant application. | |
| | - | 7.7, 8.6, 8.7 | 1 | Product/Service Realization | - The researcher incorporates collaborator's feedback into the research paper. | |
| | - | 7.7, 8.6, 8.7 | 1 | Product/Service Realization | - The researcher adjusts research parameters. | |
| | 8.1.4 | 6.4 | 1 | Product/Service Realization | - The lab director procures the resources needed for the research project. | Two activities address multiple MSS requirements in both MSSs. |
| | 8.1, 8.2 | 8.1 | 1 | Product/Service Realization | - The researcher performs research. | |
| | | **Total** | **7** | **Current activities in total address MSSs requirements.** | | |
| New activities added | - | 7.1 | 1 | Managerial | - The lab director communicates the feedback-handling process through email. | Two activities, each one addresses a single ISO 10002 MSS requirement. |
| | - | 7.9 | 1 | Managerial | - The lab director closes feedback. | |
| | - | 5, 6.1, 6.3 | 1 | Managerial | - The lab director identifies the lab's interested parties. | Six activities, each one addresses multiple ISO 10002 MSS requirements. |
| | - | 5, 6.1, 6.3 | 1 | Review/ Managerial | - The lab director analyzes interested parties' requirements. | |
| | - | 7.2, 7.3, 7.5 | 1 | Managerial | - The lab director registers feedback in a spreadsheet. | |
| | - | 7.7, 8.6, 8.7 | 1 | Managerial | - The lab director applies other corrective actions to address feedback. | |
| | - | 7.6, 8.2 | 1 | Review/ Managerial | - The lab director investigates feedback. | |
| | - | 7.7, 7.8 | 1 | Managerial | - The lab director communicates actions taken through email. | |
| | - | 7.4 | 1 | Managerial | - The lab director acknowledges feedback with email. | Two activities address a single ISO 10002 MSS requirement. |
| | - | 7.4 | 1 | Managerial | - The lab director acknowledges feedback verbally. | |
| | 8.1.1, 8.1.2, 8.2 | - | 1 | Review/ Managerial | - The lab director and researchers review the lab's OHS documentation. | Two activities, each one addresses multiple ISO 45001 MSS requirements. |
| | 8.1.2, 8.1.4 | - | 1 | Review | - The researcher applies a checklist to review research materials. | |

**Table 7.7 (continued): CSL4 Output ISO 45001 & ISO 10002 MS - current and added activities**

| | Clauses | | # of activities | Activity Type | Activities description | Comments |
|---|---|---|---|---|---|---|
| | ISO 45001 | ISO 10002 | | | | |
| New activities added | 8.1.1 | 5.4 | 1 | Managerial | - The lab director trains students in OHS and FHP to identify and understand laboratory hazards. | Seven activities address multiple MSS requirements in both MSs. |
| | 9.1 | 8.1 | 1 | Managerial | - The lab director measures the performance of research projects. | |
| | 9.1 | 8.2, 8.4 | 1 | Managerial | - The lab director monitors research performance. | |
| | 10.2, 10.3 | 7.7, 8.6, 8.7 | 1 | Managerial | - The lab director applies corrective actions related to OH&S issues. | |
| | 9.1 | 8.3 | 1 | Review/ Managerial | - The lab director evaluates performance every year. | |
| | 9.2 | 8.5 | 1 | Review/ Managerial | - The lab director performs an annual OHS and FHP internal audit. | |
| | 9.3 | 8.6, 8.7 | 1 | Review/ Managerial | - The lab director reviews lab performance at least once a year. | |
| | Total | | 19 | new activities in total needed to fulfill the MSS requirements. | | |

## 7.3 Comparison of systems (original versus resultant)

The original and the resultant MSs from both the standardization and integration processes are compared in this section.

### 7.3.1 Standardization in CSL1 & CSL2

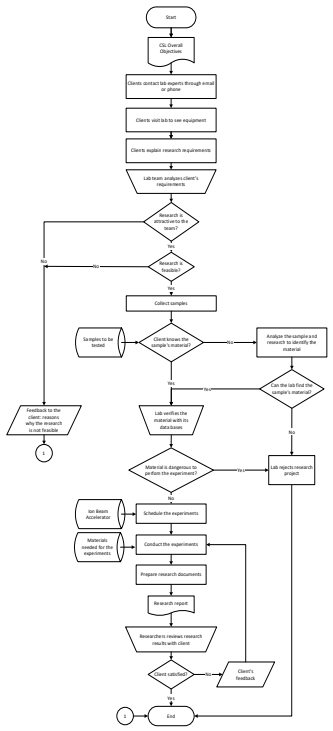
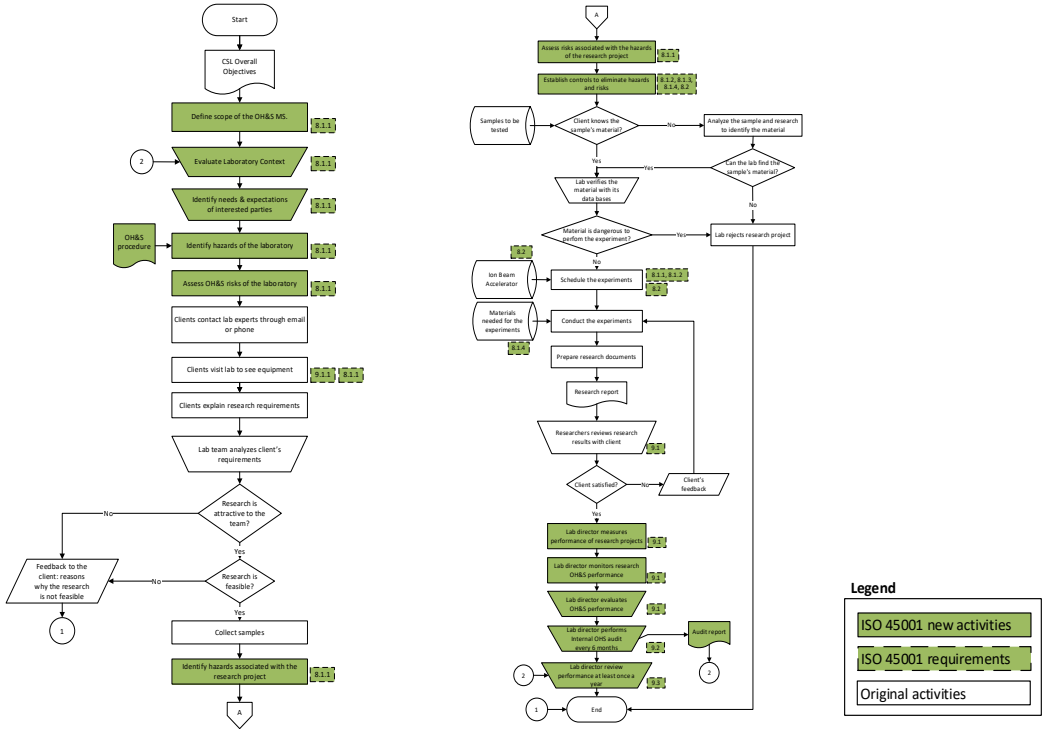
In both CSLs, an assimilative standard was used to standardize their MSs (ISO 45001 for CSL1 and ISO 9001 for CSL2). Current CSLs are described and depicted in sections 4.1.1 and 4.1.2. Resultant MSs are described and displayed in section 5.4.2.

Regarding clauses type, the common provisions utilized in both CSLs (9.1, 9.2, 9.3) result in the addition of activities in the MSs to fulfill the requirements. Although these clauses are the same for both CSLs, the focus for each CSL would be different depending on the MS objectives. For example, for clause 9.1 in CLS1, the lab director would develop OH&S KPIs for the laboratory and each research project (e.g., #incidents closed/#incidents reported) and monitor these KPIs through different methods, including lab inspections and tracking of incidents and researchers' safety suggestions. In CSL2, clause 9.1 is fulfilled by establishing quality KPIs for the laboratory (e.g., # of non-conformities) and research projects (e.g., % of successful Research Proposals) and their monitoring in an electronic document.

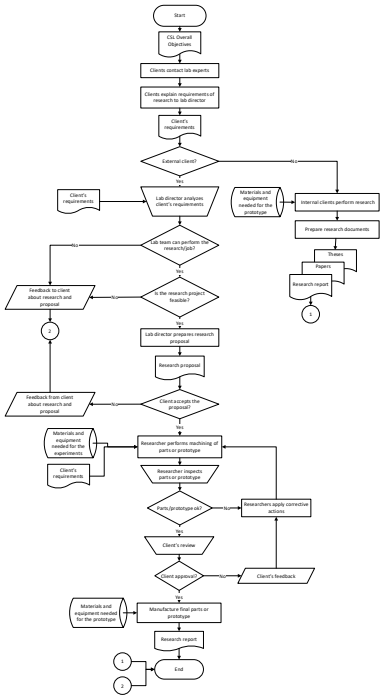
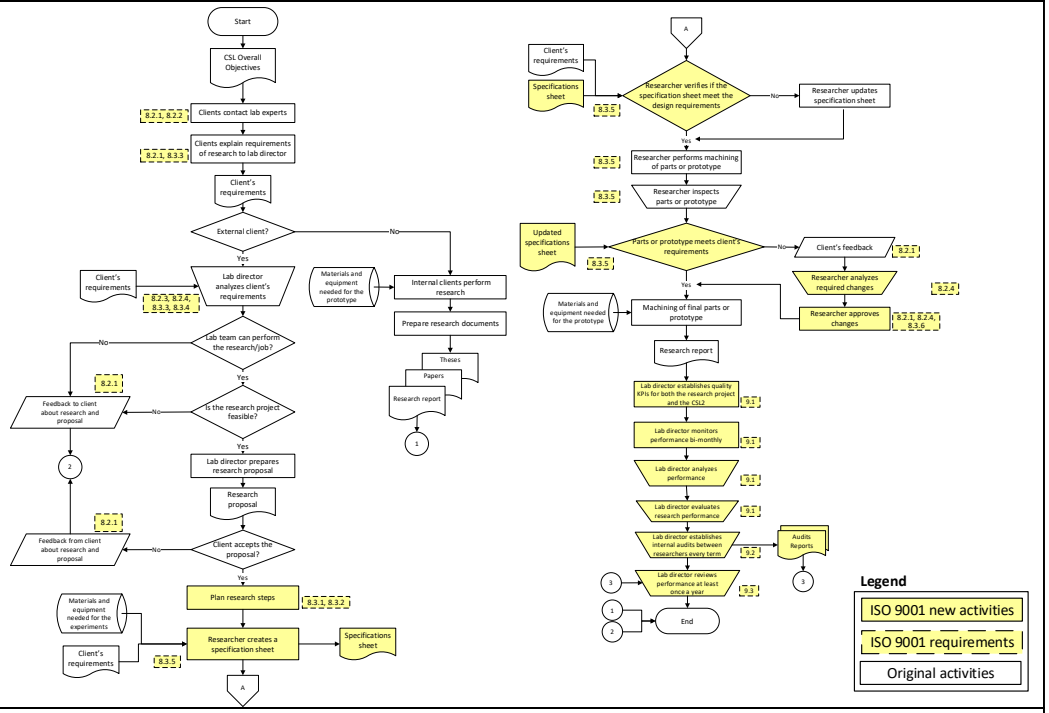
For the specific clauses in both CSLs (CSL1: 8.1, 8.2, CSL2: 8.2, 8.3), the requirements can be fulfilled by either adding new activities to the MSs or modifying current activities to fulfill the requirements. For example, in CSL1, the activities added are related to identifying hazards and assessing the risks of the laboratory and each research project (8.1.1). These activities include developing a Risk Register to document the labs' OH&S risks. For CSL2, a critical activity added is the development of a Specification Sheet for each component requested. This Specification Sheet allows to formally document the product/service requirements (clause 8.3.5).

Figures 7.5 and 7.6 show the comparison between the original and resultant MSs for CSL1 and CSL2, respectively.

## Figure 7.5: CSL1 Original and Resultant MSs Comparison

| CSL1 - Original and Resultant MSs Comparison | | |
|---|---|---|
| **MS Elements** | **Original MS** | **Resultant Standardized MS** |
| **Objectives** | The current objectives focus on routine activities. | Additional objectives were added to comply with the requirements of ISO 45001 (e.g., develop a risk register to document the lab's risks.) |
| **Processes** |  |  |
| | Twelve activities in total (nine value-added & three review activities). | Twenty-five activities in total: Thirteen are new (eight managerial & five review/managerial activities), three would need to be slightly modified (two P/S realization & one review activity), and nine need no change. |
| **Resources** | Resources needed to perform daily activities. | Resources needed to implement new activities or modify the current ones (e.g., time and a template for the researcher to develop a Job Hazard Analysis for each research project.) |

## Figure 7.6: CSL2 Original and Resultant MSs Comparison

| CSL2 - Original and Resultant MSs Comparison | | |
|---|---|---|
| **MS Elements** | **Original MS** | **Resultant Standardized MS** |
| **Objectives** | The current objectives focuses on routine activities. | Additional objectives were added to comply with the requirements of ISO 9001 fully (e.g., prepare a Specification Sheet for requested components). |
| **Processes** |  |  |
| | Eleven activities in total (eight value-added & three review activities). | Twenty activities in total: Ten are new (three P/S realization, two managerial, four review/managerial & one review activities), five would need to be slightly modified (three P/S realization & two review activities), and five activities would require no change. |
| **Resources** | Resources needed to perform daily activities. | Resources needed to implement new activities or modify the current ones (e.g., time and a computer for the researcher to prepare the components Specifications Sheets.) |

### 7.3.2 Integration in CSL3 & CSL4

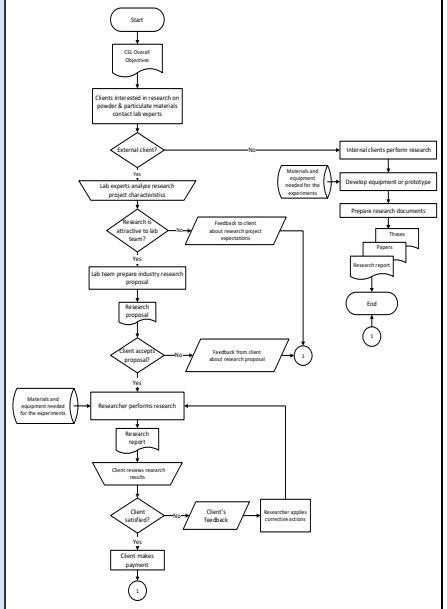
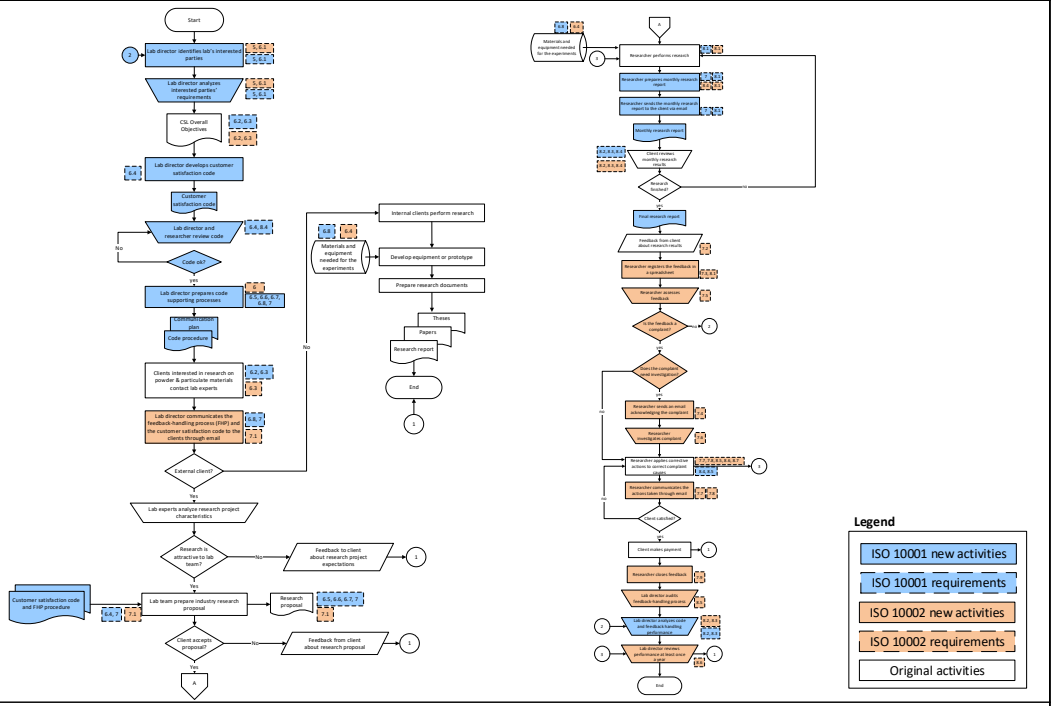
Similar to the previous section, this section compares the original and resultant MSs in CSL3 and CSL4. A "*full integration"* (Karapetrovic, 2003) of two MSs based on augmentative MSSs was applied for CSL3. A "*partial integration"* (Karapetrovic, 2003) of MSs based on an augmentative and an assimilative standard was illustrated for CSL4. The current CSLs' MSs are described and depicted in sections 4.1.3 and 4.1.4 of this thesis. Resultant MSs are described in section 6.4.2.

Regarding activities (either current or added) that address MSS requirements in both MSSs, CSL3 has eleven activities versus CSL4, which has eight activities that address clauses in both MSSs. This difference shows that it is easier to integrate requirements from the same type of MSSs (augmentative MSSs) as in CSL3. In addition, having a similar high-level structure (HLS) facilitates the integration of requirements. An activity in CSL3 MS that clearly illustrates the integration between the two augmentative MSs is the *"preparation of the Monthly Research Report."* By preparing this report, which includes a survey to measure the satisfaction with the code and the FHP, the laboratory meets multiple requirements for both MSs (ISO 10001: 7, 8.1 and ISO 10002: 8.1, 8.4).

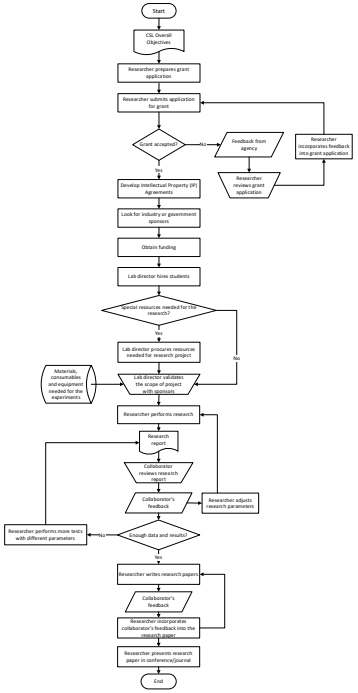
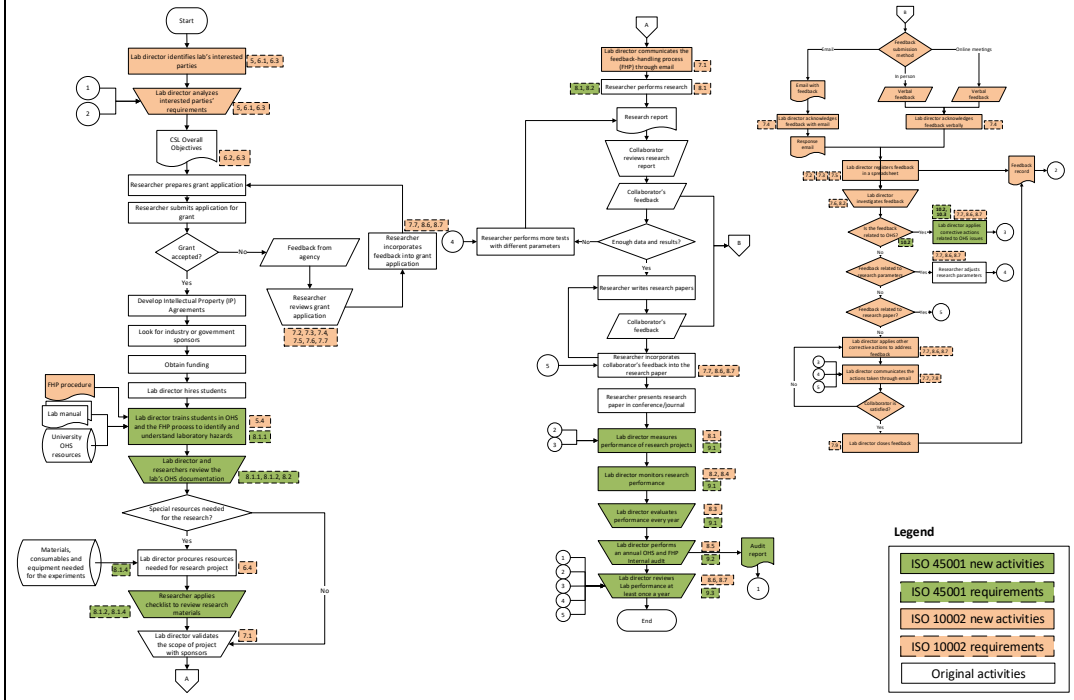
For CSL4, although clause 10 of ISO 45001 was not initially considered for integration, it was identified that the ISO 10002-based process added to gather collaborator's feedback could also be used to report OH&S issues (e.g., incidents, unsafe behaviours and conditions) and, therefore, improve the OH&S MS. This additional integration is shown in the flowchart in Figure 7.8.

Figures 7.7 and 7.8 show the comparison between the original and resultant MSs for CSL3 and CSL4, respectively.

## Figure 7.7: CSL3 Original and Resultant MSs Comparison

| CSL3 - Original and Resultant MSs Comparison | | |
|---|---|---|
| **MS Elements** | **Original MS** | **Resultant Integrated MS** |
| **Objectives** | The current objectives focuses on routine activities. | Additional objectives were added to comply with the requirements of ISO 10001 and ISO 10002 (e.g., prepare a monthly Research Progress Report with useful information for the client, establish a simple complaint handling process). |
| **Processes** |  |   |
| | Ten activities in total (eight value-added & two review activities) | Twenty-seven activities in total: Seventeen are new (two P/S realization, eight managerial, one review & six review/managerial activities), five would need to be slightly modified (three P/S realization, one managerial & one review activity), and five activities need no change. |
| **Resources** | Resources needed to perform daily activities. | Resources needed to implement new activities or modify the current ones (e.g., Monthly Research Progress Report template, a template to register client's feedback about research.) |

## Figure 7.8: CSL4 Original and Resultant MSs Comparison

| CSL4 - Original and Resultant MSs Comparison | | |
|---|---|---|
| **MS Elements** | **Original MS** | **Resultant Integrated MS** |
| **Objectives** | The current objectives focuses on routine activities. | Additional objectives were added to comply with the requirements of ISO 45001 and ISO 10002 fully (e.g., establish an OH&S internal audit schedule, implement a simple complaint handling process). |
| **Processes** |  |  |
| | Seventeen activities in total (fourteen value-added activities & three review activities). | Thirty-six activities in total: Nineteen are new (one review, six review/managerial & twelve managerial activities), seven would need to be slightly modified (five P/S realization & two review activities), and ten activities need no change. |
| **Resources** | Resources needed to perform daily activities. | Resources needed to implement new activities or modify the current ones (e.g., time for the lab director to conduct the OH&S internal audit, a template to register client's feedback about research). |

## 7.4 Comparison of standardization and integration processes

This section shows a comparison of all the different steps for the standardization and integration processes following the IUMSS methodology. Table 7.8 shows the differences and commonalities between standardization and integration processes.

**Table 7.8: Standardization and integration processes comparison**

| | Comments on processes (similarities and differences) | |
|---|---|---|
| **IUMSS Steps** | **Standardization Processes CSL1 & CSL2** | **Integration Processes CSL3 & CSL4** |
| 3.1 Lead | In both standardization and integration processes, the CSLs' directors are responsible for leading these processes. | |
| 3.2 Determine the scope | The scope for both CSLs includes three common and two specific assimilative MSSs clauses. CSL1 (ISO 45001), CSL2 (ISO 9001). | • The scope for CSL3 is to fully integrate two MSs based on augmentative MSSs (ISO 10001 & ISO 10002).<br>• The scope for CSL4 is to partially integrate two MSs based on some clauses of an assimilative MSS (ISO 45001) and all the clauses of an augmentative MSS (ISO 10002). |
| 3.3 Plan the implementation | The CSLs directors would establish the plan to set the standardization and integration goals, priorities and deadlines. | |
| 3.4 Connect MSSs requirements & CSLs MSs | | |
| 3.4.1 Structure CSLs' MSs | The structure of the input MSs of the four CSLs was depicted in flowcharts in Chapter 4 of this thesis. | |
| 3.4.2 Structure MSSs requirements | • Three common and two specific clauses are implemented in both CSLs.<br>• The common clauses are related to the performance evaluation process: 9.1, 9.2, 9.3.<br>• The specific clauses for each CSL are related to operations:<br>CSL1: 8.1, 8.2.<br>CSL2: 8.2, 8.3. | • Integration in CSL3 covers all clauses of ISO 10001 & ISO 10002.<br>• Integration in CSL4 involves all clauses of ISO 10002 and clauses 8.1, 8.2, 9.1, 9.2, 9.3 of ISO 45001. |
| 3.4.3 Mapping MSSs requirements vs CSLs MSs | For the mapping, a "matrix" approach was used to analyze the impact of MSSs requirements on CSLs MSs. | For the mapping, the "juxtaposition approach" was used to analyze the impact of MSSs requirements on CSLs MSs. |
| 3.5 Incorporate MSSs requirements into CSLs MSs | | |
| 3.5.1 Identify & analyze gaps | Tables with colour-coding to illustrate the level of fulfillment were used in both gap analysis processes. | |
| 3.5.2 Close gaps | The output CSLs MSs that include the added or modified processes were depicted in flowcharts in Chapters 5 and 6 of this thesis for both the standardization and integration processes. | |

**Table 7.8 (continued): Standardization and integration processes comparison**

| IUMSS Steps | Standardization Processes CSL1 & CSL2 | Integration Processes CSL3 & CSL4 |
|---|---|---|
| 3.5.3 Confirm gaps closure | There was one type of verification which was about the implementation of the requirements of the MSSs. | • There were three types of verification of gaps closure.<br>• The first involved the verification of the implementation of the requirements of each MSS, the second one involved verifying the existence of a component that addresses the MSS requirement, and the third one was the verification of the integration of the MSSs requirements into the CSLs MSs. |

As shown in Table 7.8, some differences can be found between the standardization and integration processes. Most of these differences (steps 3.2, 3.4.2, 3.5.3) are related to the CSL MS scope (MSS and clauses considered) and the implementation level (full or partial) in each process. For the mapping process (3.4.3), a different approach was used in each process to analyze the impact of the MSSs requirements on the CSLs MSs.

Regarding similarities, those can be found in steps (3.1, 3.3, 3.4.1, 3.5.1, 3.5.2) and are concerned with the management of the standardization or integration project and the tools used in those steps (e.g., flowcharts to represent the MSs, tables and colour coding to illustrate the gaps).

The comparison conducted in this section shows that the IUMSS methodology is applicable for the standardization and integration process with slight differences.

## 7.5 Summary

This chapter presented four types of comparisons among the CSLs MSs. Sub-chapter 7.1 showed the comparison between the original CLSs MSs used for standardization (CSL1 & CSL2) and the ones used for integration (CSL2 & CSL3). Similarities were found among CSL1 and CSL2 MSs regarding deliverables, stakeholders and facilities. The differences between them were related to their processes' complexity and the number of personnel. The comparison between the original MSs of CSL3 and CSL4 showed more differences than similarities, including external clients from different industries and differences in the technological level of their equipment.

The comparisons between CSL3 & CSL4 in Sub-chapter 7.2 showed that the *"full integration"* of MSs based on augmentative MSSs was more efficient than the *"partial integration"* of MSs based on an augmentative and an assimilative MSS. This efficiency is

demonstrated in more activities that simultaneously fulfill various augmentative MSSs' requirements.

The comparisons in Sub-chapter 7.3 between the original and resultant MSs for CSL4 showed that the "*partial integration,"* considering clauses 8 and 9 of ISO 45001, was not as effective as intended as only the verification activities were the ones for which opportunities for integration were identified.

Sub-chapter 7.4 compared the standardization and integration processes of CSLs MSs using the IUMSS methodology. This analysis showed that the methodology is relevant for standardization and integration supported by tools like flowcharts, tables, colour coding, and the *"juxtaposition"* and *"matrix"* approaches.

# 8 Conclusions

This chapter finalizes the thesis by summarizing the previous chapters, presenting the main contributions and limitations of the research, and finally giving recommendations for future research.

## 8.1 Summary

Chapter 2 of this thesis produced a literature review on QMSs in research laboratories, OH&S MSs in research laboratories and integration of MSs, including the Integrated Use of Management System Standards (IUMSS) methodology, followed by the motivation for the research and the research objectives. Chapter 3 explained the methodology used for this research project.

Chapter 4 presented a description of the current MSs of the four case study laboratories (CSLs) and an analysis of the MSSs to be applied to these case studies (i.e., ISO 9001, ISO 45001, ISO 10001, ISO 10002).

Chapter 5 showed the use of the IUMSS methodology for the implementation of the ISO 45001 and ISO 9001 requirements to the OH&SMS and QMS of CSL1 and CSL2, respectively.

Chapter 6 presented two examples of integration of MSs following the IUMSS methodology. The first example showed the integration of two augmenting standards (ISO 10001 and ISO 10002) in CSL3. The integration of a system based on an MSS (ISO 45001) and an augmenting standard (ISO 10002) was illustrated in CSL4 in the second example.

Chapter 7 introduced four types of comparisons among the management systems of the CSLs. In the first type of comparison, the initial MSs (i.e., before standardization or integration) were contrasted. The second comparison involved the MSs resulting from the standardization or integration process. In the third comparison, the initial and resulting MSs of each CSL were compared. The fourth comparison contrasted the standardization and the integration processes.

## 8.2 Contributions

The main contributions of this thesis are presented next:

- This thesis showed the theoretical standardization and integration of MSs based on ISO MSSs through four university research laboratories (CSLs) from different faculties and two universities in two countries following the IUMSS methodology. The four CSLs provided unique opportunities to illustrate diverse scenarios for the standardization (in CSL1 & CSL2) and integration processes (in CSL3 & CSL4) applying the steps of the IUMSS methodology in university research laboratories. A literature search has shown that there is not much research on MSs' standardization and integration in university research laboratories.
- As described in the literature review, some previous studies explored the integration of MSs based on augmenting MSSs. However, to the best of my knowledge, this research presented CSL3 and CSL4 as the first cases to explore the full integration of augmenting standards (ISO 10001 & ISO 10002) and a customer satisfaction MS based on ISO 10002 (full implementation) with an OH&SMS based on ISO 45001 (partial integration) in a university research laboratory.
- As far as the literature search conducted has shown, this research is the first to present the application of the new versions of the IUMSS handbook, ISO 45001, ISO 10001 & ISO 10002 MSSs in university research laboratories. The CSLs served as examples of how universities could implement and integrate ISO MSSs or other MSSs to enhance their existing MSs.
- During the application of the IUMSS methodology in the CSLs, two different approaches (matrix and juxtaposition) were used to map the MSSs' requirements into the CSLs' MSs. Although the new IUMSS Handbook defined both methods, it only showed examples of the matrix approach. CSL3 & CSL4 exemplified the use of the juxtaposition approach.
- To "*maintain and improve*" (section 3.6 of IUMSS handbook) the standardization or integration processes, an annual general review could be performed to review the fulfilment of the new requirements, such as the results of internal audits (level of compliance of corrective actions) or the level of implementation of risks' controls. Also, as consistent monitoring and review of the MS is critical for its maintenance and improvement (ISO, 2018e), the CSLs might choose which key performance indicators from critical processes to monitor and review on a bimonthly or quarterly basis.

- Regarding the "*application of lessons learned*" (section 3.7 of IUMSS handbook), the result of the analysis would serve as guidance for future MSS implementation endeavours in other universities' CSLs. Opportunities for further integration with different standards could also be explored. For example, CSL1 could benefit from integration with International Atomic Energy Agency standards (IAEA), IAEA GS-R-3-2006 "*The Management System for Facilities and Activities*" and IAEA GS-R-2-2002 "*Preparedness and Response for a Nuclear or Radiological Emergency*."
- Regarding the standardization processes, a representative number of clauses was chosen to exemplify this process. From them, three common clauses were used in both CSL1 and CSL2. After implementing these common clauses, it was observed that this standardization required the addition of the same activities into the MS. However, the focus of these activities was different depending on the MS. For example, clause 9.3 should focus on OH&S aspects in CSL1 (e.g., monitor number of incidents that occurred during research project activities and their root causes) and quality aspects (e.g., monitor results of quality testing during the research project) in CSL2.
- Regarding CSL4, although the integration scope only included five clauses of ISO 45001 (partial integration), which do not contain clause 6.2, there needs to be an update of the objectives of the CSL4 MS to include the OH&S aspects. The inclusion of OH&S-related objectives would be critical to guide the implementation of clauses 8.1, 8.2, 9.1, 9.2 and 9.3 of ISO 45001.
- CSL4 showed an example of the integration of a customer satisfaction MS based on ISO 10002 (full implementation) with an OH&SMS based on ISO 45001 (partial integration) in a university research laboratory. After analyzing the integration, it was noticed that ISO 45001 was not as beneficial as could be if the integration base had been ISO 45001 entirely and enhanced with an augmenting MSS such as ISO 10002. For instance, clause 10.2 of ISO 45001 could be effectively enhanced with the FHP provided by ISO 10002. Under that scenario, OH&S incidents could be treated as "complains" in the ISO 10002 FHP. Therefore, it may be better to integrate an MSS such as ISO 9001 or ISO 45001 and then enhance it by incorporating an MSS such as ISO 10001 or ISO 10002.

## 8.3 Limitations of research

Some limitations that should be considered are:

- The scope of this research was limited to four CSLs: three CSLs from a university located in Europe and one from North America. Therefore, fully generalized conclusions cannot be established, as each CSL had its own characteristics.
- The scope of the research was focused on the theoretical implementation of standardization and integration processes. Therefore sections 3.6 and 3.7 of the IUMSS methodology were not developed but were addressed as conclusions.
- The information input used for the CSLs analysis was based only on semi-structured interviews and documentation. It was not verified through observations.
- Due to time constraints, the time from laboratories' personnel was limited. As a result, only one or two interviews with them were performed. In addition, it was not possible to perform a complete, full-scale baseline audit in each of the CSLs MSs.
- The results were not compared with any other similar study since there was no previous analysis of the standardization or integration in university research laboratories.

## 8.4 Future research

Some suggestions for future research are presented as follows:

- Application of the IUMSS methodology to standardize and integrate the requirements of MSSs into MSs of other university research laboratories.
- Exploration of the augmentation of an OH&S MS based on ISO 45001 with a feedback-handling MS based on ISO 10002 in a university research laboratory.
- Study the challenges and applicability of suggestions after implementing ISO standards and/or after the integration of MSs based on MSSs requirements in university research laboratories.
- Application of a full-scale audit of universities' research laboratories MSs and identification gaps between the MSs and ISO standards or other interest standards.
- Investigation of the application of other MSSs, not necessarily ISO standards, in university research laboratories.

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# Appendix A: Literature Review

The following tables show the detailed search strategies and the traceability for each topic. In some cases, too many articles appeared during a first preliminary search. Then, the search was refine in a second round.

Table A1 shows the search strategy one conducted in the five databases for the topic standardized management systems and laboratories.

**Table A1: Search Strategy 1: Standardized management systems and laboratories**

| Search Strategy 1: Standardized management systems and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards.<br>Date of search: 07/24/2020<br>ab("management system" OR "standardized management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories")<br>Date: After 2000 - Source type: Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals | 76 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020<br>With “laboratories” OR “laboratory” were 1967 results: ( ABS ( "management system" OR "standardized management system" ) AND ABS ( "research laboratory" OR "research laboratories" OR "laboratories" OR "laboratory" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999.<br>*( ABS ( "management system" OR "standardized management system" ) AND ABS ( "research laboratory" OR "research laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 | 69 |
| Web of Science | Search carried out in Web of Science 2000 onwards. Date of search 07/27/2020<br>With “laboratories” OR “laboratory” were 1851 results: ("management system" OR "standardized management system") AND TOPIC: ("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") Refined by: [excluding] DOCUMENT TYPES: ( MEETING ABSTRACT OR EARLY ACCESS OR SOFTWARE REVIEW OR BOOK CHAPTER OR NEWS ITEM OR CORRECTION OR EDITORIAL MATERIAL OR LETTER OR DATA PAPER ) Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.<br>*("management system" OR "standardized management system") AND TOPIC: ("research laboratory" OR "research laboratories")<br>Refined by: [excluding] DOCUMENT TYPES: ( BOOK CHAPTER )<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. | 74 |

| Search Strategy 1: Standardized management systems and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| Compendex | Search carried out in Web of Science 2000 onwards. Date of search 07/27/2020<br>With “laboratories” OR “laboratory” were 483 results: found in Compendex for 2000-2020: ((("standardized management systems" OR "management systems") WN AB) AND (("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") WN AB)) AND (English WN LA) - ({st} OR {ch} OR {bk} OR {ds}) WN DT<br>*Found in Compendex for 2000-2020: ((((((("standardized management systems" OR "management systems") WN AB) AND (("research laboratory" OR "research laboratories") WN AB)) AND (English WN LA)) NOT (({ch} OR {bk} OR {cp}) WN DT))) | 28 |
| Emerald Insight | Search carried out in Emerald Insight 2000 onwards. Date of search 08/06/2020<br>From 2000 until 2020 - (content-type:article) AND (abstract:"management syste*" AND (abstract:"laborator*")) | 19 |
| | **Total** | **266** |

Table A2 shows the search strategy conducted in the five databases for the topic quality management system and laboratories.

**Table A2: Search Strategy 2: Quality management system and laboratories**

| Search Strategy 2: Quality management system and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/24/2020<br>ab("quality management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories"<br>Date: After 2000<br>Source type: Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals | 17 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020<br>With “laboratory” OR “laboratories”: 362 results. ( ABS ( "quality management system" ) AND ABS ( "research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999<br>*( ABS ( "quality management system" ) AND ABS ( "research laboratory" OR "research laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 | 18 |
| Web of Science | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020<br>With “laboratory” OR “laboratories”: 250 results. TOPIC: ("quality management system") AND TOPIC: ("research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories")<br>Refined by: [excluding] DOCUMENT TYPES: ( MEETING ABSTRACT OR EDITORIAL MATERIAL OR LETTER OR BOOK CHAPTER OR EARLY ACCESS OR NEWS ITEM )<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.<br>*("quality management system") AND TOPIC: ("research laboratory" OR "research laboratories") | 14 |

| Search Strategy 2: Quality management system and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| | Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. | |
| Compendex | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/27/2020 (((((("quality management systems") WN AB) AND (("research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories") WN AB)) AND (English WN LA)) NOT (({st} OR {bk} OR {ch}) WN DT)) | 13 |
| Emerald Insight | Search carried out in ABI Inform Complete 2000 onwards. Date of search 08/06/2020 From 2000 until 2020 (content-type:article) AND (abstract:"quality management system*" AND (abstract:"laborator*")) | 5 |
| | **Total** | **67** |

Table A3 shows the search strategy conducted in the five databases for the topic occupational health and safety management system and laboratories.

**Table A3: Occupational health and safety management system and laboratories**

| Search Strategy 3: Occupational health and safety management system and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/24/2020 ab("ohsas 18001" OR "ISO 45001" ) AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") Source type: Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals | 1 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020 ( ABS ( "ohsas 18001" OR "ISO 45001" ) AND ABS ( "laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 | 5 |
| Web of Science | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020 ("ohsas 18001" OR "ISO 45001") AND TOPIC: ("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. | 4 |
| Compendex | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020 found in Compendex for 2000-2020: ((("ohsas 18001" OR "ISO 45001") WN AB) AND (("research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories") WN AB)) AND (English WN LA) | 5 |
| Emerald Insight | Search carried out in Scopus 2000 onwards. Date of search 08/06/2020 (content-type:article) AND (abstract:"ISO 45001 or OHSAS 18001" AND (abstract:"laborator*")) | 0 |
| | **Total** | **15** |

Table A4 shows the search strategy conducted in the five databases for the topic occupational health and safety management system

**Table A4: Search Strategy 4: Occupational health and safety management system**

| Search Strategy 4: Occupational health and safety management system | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/24/2020<br>ab("ISO 45001")<br>Date: After 2000<br>Source type: Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals<br>Language: English | 26 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020<br>Search considering OR "ohsas 18001" were 223 results: ABS ( "ohsas 18001" OR "ISO 45001" ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999<br>*ABS ( "ISO 45001" ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 | 30 |
| Web of Science | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020<br>Search considering OR "ohsas 18001" were 240 results: ("ohsas 18001" OR "ISO 45001")<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.<br>*("ISO 45001") Refined by: [excluding] DOCUMENT TYPES: ( BOOK CHAPTER OR LETTER )<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. | 36 |
| Compendex | Search carried out in Compendex 2000 onwards. Date of search 07/27/2020<br>Search considering OR "ohsas 18001" were 204 results: found in Compendex for 2000-2020: (("ohsas 18001" OR "ISO 45001") WN AB) AND (English WN LA)<br>*found in Compendex for 2000-2020: (("ISO 45001") WN AB) AND (English WN LA) - {st} WN DT | 29 |
| Emerald Insight | Search carried out in Emerald Insight 2000 onwards. Date of search 08/06/2020<br>From 2000 until 2020 (content-type:article) AND (abstract:"ISO 45001") | 2 |
| | **Total** | **123** |

Table A5 shows the search strategy conducted in the five databases for the topic ISO 9001 and laboratories.

## Table A5: Search Strategy 5: ISO 9001 and laboratories

| Search Strategy 5: ISO 9001 and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/2/2020<br>ab("ISO 9001" OR "ISO 10001" OR "ISO 10002") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories")<br>Date: After 2000, Source type: Scholarly Journals | 12 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020<br>( ABS ( "ISO 9001" OR "ISO 10001" OR "ISO 10002" ) AND ABS ( "research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 AND ( LIMIT-TO ( LANGUAGE , "English" ) ) | 69 |
| Web of Science | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020<br>("ISO 9001" OR "ISO 10001" OR "ISO 10002") AND TOPIC: ("research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories") Refined by: [excluding] DOCUMENT TYPES: (OTHER OR EDITORIAL OR DATA SET OR MEETING OR BOOK OR REFERENCE MATERIAL OR LETTER OR ABSTRACT OR CLINICAL TRIAL OR UNSPECIFIED OR PATENT ) AND LANGUAGES: ( ENGLISH )<br>Timespan: 2000-2020. Databases: WOS, BCI, BIOSIS, CABI, CCC, DRCI, DIIDW, FSTA, KJD, MEDLINE, RSCI, SCIELO, ZOOREC. Search language=Auto | 69 |
| Compendex | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020<br>((("ISO 9001" OR "ISO 10001" OR "ISO 10002") WN AB) AND (("research laboratory" OR "research laboratories" or "laboratory" or "laboratories") WN AB)) AND (English WN LA) | 53 |
| Emerald Insight | Search carried out in Scopus 2000 onwards. Date of search 08/06/2020<br>From 2000 until 2020 - (content-type:article) AND (abstract:"ISO 9001" OR "ISO 10002" OR "ISO 10001") AND (abstract:"laborator*")) | 3 |
| | **Total** | **206** |

Table A6 shows the search strategy conducted in the five databases for the topic customer satisfaction and laboratories.

## Table A6: Search Strategy 6: Customer satisfaction and laboratories

| Search Strategy 6: Customer satisfaction and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search 07/24/2020<br>ab("customer satisfaction") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories")<br>Date: After 2000 - Source type: Conference Papers & Proceedings, Dissertations & Theses, Scholarly Journals | 26 |

| Search Strategy 6: Customer satisfaction and laboratories | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 07/24/2020<br>With “laboratory” OR “laboratories”: 130 documents. ( ABS ( "customer satisfaction" ) AND ABS ( "laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999<br>*( ABS ( "customer satisfaction" ) AND ABS ( "research laboratory" OR "research laboratories" ) ) AND DOCTYPE ( ar OR re ) AND PUBYEAR > 1999 | 2 |
| Web of Science | Search carried out in Scopus 2000 onwards. Date of search 07/27/2020<br>With “laboratory” OR “laboratories”: 160 documents. ("customer satisfaction") AND TOPIC: ("research laboratory" OR "research laboratories" OR "laboratory" OR "laboratories")<br>Refined by: [excluding] DOCUMENT TYPES: ( BOOK CHAPTER OR EARLY ACCESS OR MEETING ABSTRACT )<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.<br>*("customer satisfaction") AND TOPIC: ("research laboratory" OR "research laboratories")<br>Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC. | 3 |
| Compendex | With “laboratory” OR “laboratories”: 61 documents. Found in Compendex for 2000-2021: ((("customer satisfaction") WN AB) AND (("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") WN AB)) AND (English WN LA) - {ip} WN DT<br>*Found in Compendex for 2000-2021: ((("customer satisfaction") WN AB) AND (("research laboratory" OR "research laboratories") WN AB)) AND (English WN LA) | 1 |
| Emerald Insight | Search carried out in Emerald Insight 2000 onwards. Date of search 08/06/2020<br>From 2000 until 2020<br>(content-type:article) AND (abstract:"customer satisfaction" AND (abstract:"laborator*")) | 11 |
| | **Total** | **43** |

Table A7 shows the search strategy conducted in the five databases for the topic management systems and integration and laboratories, research facilities, institutions.

## Table A7: Search Strategy 7: Management Systems and Integration and laboratories or (research (facilities, institutions, teaching))

| Search Strategy 7: Management Systems and Integration and laboratories or (research (facilities, institutions, teaching)) | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete 2000 onwards. Date of search: 21/02/2021<br>ab("management system*") AND ab("integrat*") AND ab("laborator*" OR "research facilit*" OR "research institut*" OR "teaching institut*") AND stype.exact("Conference Papers & Proceedings" OR "Scholarly Journals" OR "Dissertations & Theses") AND la.exact("English") AND pd(>20001231) | 20 |
| Scopus | Search carried out in Scopus 2000 onwards. Date of search 09/03/2021<br>( ABS ( "management system*" ) AND ABS ( integrat* ) AND ABS ( iso ) AND ABS ( ( "research" AND ( "laborator*" OR "Institut*" OR "facilit*" ) ) ) ) AND PUBYEAR > 1999 | 61 |
| Web of Science | Search carried out In Web of Science 2000 onwards. Date of search: 09/03/2021<br>TOPIC: ("management system*") AND TOPIC: (integrat*) AND TOPIC: (ISO) AND TOPIC: ("research laborator*" OR "research facilit*" OR "research institut*" OR "teaching") | 15 |
| Compendex | Search carried out In Compendex 2000 onwards. Date of search: 09/03/2021<br>found in Compendex for 2000-2022: (((((("management system*") WN AB) AND ((integrat*) WN AB)) AND ((ISO) WN AB)) AND (((Research AND (laborator* OR institut* OR facilit* OR teaching))) WN AB)) | 18 |
| Emerald Insight | Search carried out in Emerald Insight 2000 onwards. Date of search 07/03/2021<br>From 2000 until 2020 - abstract:"management system*" AND (abstract:"integrat*") AND (abstract:"ISO") AND (abstract:"research") | 38 |
| | **Total** | **152** |

Table A8 shows the search strategy conducted in the five databases for the topic IUMSS.

## Table A8: Search Strategy 8: Integrated use of management system standards - IUMSS

| Search Strategy 8: Integrated use of management system standards - IUMSS | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete. Date of search: 28/03/2021<br>("IUMSS" OR "Integrated use of management system standards") NOT stype.exact("Magazines") | 25 |

| Search Strategy 8: Integrated use of management system standards - IUMSS | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| Scopus | Search carried out in Scopus. Date of search: 28/03/2021<br>ALL ("IUMSS" OR "Integrated Use of Management System Standards") AND (EXCLUDE (DOCTYPE, "bk") OR EXCLUDE (DOCTYPE, "ch")) | 52 |
| Web of Science | Search carried out in Web of Science. Date of search: 28/03/2021<br>TOPIC: ("Integrated Use of Management System Standards ") OR TOPIC: (“IUMSS”) | 0 |
| Compendex | Search carried out in Compendex. Date of search: 28/03/2021<br>"integrated use of management system standards" OR "IUMSS" | 0 |
| Emerald Insight | Search carried out in Emerald Insight. Date of search: 28/03/2021<br>(content-type:article OR content-type:"case study") AND ("integrated use of management system standards" OR ("IUMSS")) | 21 |
| | **Total** | **98** |

Table A9 shows the search strategy conducted in the five databases for the topic OH&SMS and laboratories.

## Table A9: Search Strategy 9: OH&SMS and laboratories

| Search Strategy 9: OH&SMS and labs | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Search carried out in ABI Inform Complete. Date of search: 15/07/2021<br>ab("occupational health and safety management system" OR "occupational safety and health management system") AND ab("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") | 1 |
| Scopus | Search carried out in Scopus. Date of search: 14/07/2021<br>( ABS ( "occupational health and safety management system" OR "occupational safety and health management system" ) AND ABS ( "laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories" ) ) AND PUBYEAR > 1999 | 8 |
| Web of Science | Search carried out in Web of Science. Date of search: 14/07/2021<br>"occupational health and safety management system" OR "occupational safety and health management system" (Topic) and "laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories" (Topic)<br>NOT Document Types: Meeting or other - Timespan: 2000-01-01 to 2021-07-01 | 4 |
| Compendex | Search carried out in Compendex. Date of search: 14/07/2021<br>((("occupational health and safety management system" OR "occupational safety and health management system") WN AB) AND (("laboratory" OR "laboratories" OR "research laboratory" OR "research laboratories") WN AB)) | 2 |

| Search Strategy 9: OH&SMS and labs | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| Emerald Insight | Search carried out in Emerald Insight. Date of search: 15/07/2021<br>abstract:"(occupational health and safety management system)" AND (abstract:"laborator*") | 0 |
| | **Total** | **15** |

Table A10 shows the search strategy conducted in the five databases for the topic ISO 10001 and ISO 10002.

**Table A10: Search Strategy 10: ISO 10001 and ISO 10002**

| Search Strategy 10: ISO 10001 and ISO 10002 | | |
|---|---|---|
| **Database** | **Search** | **Results** |
| ABI Inform Complete | Date of search 08/24/2020<br>ab("ISO 10001" OR "ISO 10002")<br>Scholarly Journals | 3 |
| Scopus | Date of search 08/24/2020<br>ABS ( "ISO 10001" OR "ISO 10002" ) | 11 |
| Web of Science | Date of search 08/24/2020<br>"ISO 10001" OR "ISO 10002" (Abstract) | 6 |
| Compendex | Date of search 08/24/2020<br>(("ISO 10001" OR "ISO 10002") WN AB) | 8 |
| Emerald Insight | Date of search 08/24/2020<br>(content-type:article OR content-type:"case study") AND ("ISO 10001" OR "ISO 10002") | 15 |
| | **Total** | **43** |

The following tables show the screening process performed in each search in order to obtain the articles that were finally included in the thesis. Table A11 shows the screening summary applied in search strategy one.

**Table A11: Screening Summary Search Strategy 1**

| Search Strategy 1: Standardized management systems and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Data Bases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **76** | **69** | **74** | **28** | **19** | **266** |
| Duplicates within same database | 1 | 0 | 0 | 0 | 0 | 1 |
| Total | 75 | 69 | 74 | 28 | 19 | 265 |

| Search Strategy 1: Standardized management systems and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Data Bases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| Duplicates between databases | | | 60 | | | 205 |
| Not relevant (First round) | | | 157 | | | 48 |
| Not relevant (Second round) | | | 25 | | | 23 |
| Not relevant (Third round) | | | 11 | | | 12 |
| **Final Results** | | | | | | **12** |

Table A12 shows the screening summary applied in search strategy two.

**Table A12: Screening Summary Search Strategy 2**

| Search Strategy 2: Quality management system and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **17** | **18** | **14** | **13** | **5** | **67** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | |
| Total | 17 | 18 | 14 | 13 | 5 | 67 |
| Duplicates between databases | | | 16 | | | 51 |
| Not relevant (First Round) | | | 16 | | | 35 |
| Not relevant (Second Round) | | | 3 | | | 32 |
| Already included in search 1 | | | 30 | | | 2 |
| Not relevant (Third Round) | | | 2 | | | 0 |
| **Final Results** | | | | | | 0 |

Table A13 shows the screening summary applied in search strategy three.

**Table A13: Screening Summary Search Strategy 3**

| Search Strategy 3: Occupational health and safety management system and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **1** | **5** | **4** | **5** | **0** | **15** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | 15 |

| Search Strategy 3: Occupational health and safety management system and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| Total | 1 | 5 | 4 | 5 | 0 | 15 |
| Duplicates between databases (Refworks) | 5 | | | | | 10 |
| Not relevant (First Round) | 3 | | | | | 7 |
| Not relevant (Second Round) | 3 | | | | | 4 |
| Already included in search 2 | 1 | | | | | 3 |
| Not relevant (Second Round) | 3 | | | | | 0 |
| **Final Results** | | | | | | 0 |

Table A14 shows the screening summary applied in search strategy four.

## Table A14: Screening Summary Search Strategy 4

| Search Strategy 4: Occupational health and safety management system | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **26** | **30** | **36** | **29** | **2** | **123** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | 123 |
| Total | 26 | 30 | 36 | 29 | 2 | 123 |
| Duplicates between databases | 40 | | | | | 83 |
| Not relevant (First Round) | 40 | | | | | 43 |
| Not relevant (Second Round) | 21 | | | | | 22 |
| Not relevant (Third round) | 11 | | | | | 11 |
| **Final Results** | | | | | | **11** |

Table A15 shows the screening summary applied in search strategy five.

## Table A15: Screening Summary Search Strategy 5

| Search Strategy 5: ISO 9001 and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **12** | **69** | **69** | **53** | **3** | **206** |
| Duplicates within same database | 0 | 1 | 0 | 3 | 0 | 4 |
| Total | 12 | 68 | 69 | 50 | 3 | 202 |
| Duplicates between databases | 56 | | | | | 146 |
| Not relevant (First round) | 60 | | | | | 86 |
| Not relevant (second round) | 50 | | | | | 36 |
| Already included in other searches | 10 | | | | | 26 |
| Not relevant (third round) | 18 | | | | | 8 |
| **Final Results** | | | | | | **8** |

Table A16 shows the screening summary applied in search strategy six.

## Table A16: Screening Summary Search Strategy 6

| Search Strategy 6: Customer satisfaction and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **26** | **2** | **3** | **1** | **11** | **43** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | 43 |
| Total | 26 | 2 | 3 | 1 | 11 | 43 |
| Duplicates between databases | 11 | | | | | 32 |
| Not relevant (First round) | 16 | | | | | 16 |
| Not relevant (second round) | 10 | | | | | 6 |
| Not relevant (third round) | 6 | | | | | 0 |
| **Final Results** | | | | | | **0** |

Table A17 shows the screening summary applied in search strategy seven.

## Table A17: Screening Summary Search Strategy 7

| Search Strategy 7: Management Systems and Integration and laboratories or (research (facilities, institutions, teaching)) | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **20** | **61** | **15** | **18** | **38** | **152** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | |
| Total | 20 | 61 | 15 | 18 | 38 | 152 |
| Duplicates between databases | 27 | | | | | 125 |
| Not relevant (First Round) | 37 | | | | | 88 |
| Not relevant (Second Round) | 32 | | | | | 56 |
| Not relevant (Third Round) | 47 | | | | | 9 |
| **Final Results** | | | | | | **9** |

Table A18 shows the screening summary applied in search strategy eight.

## Table A18: Screening Summary Search Strategy 8

| Search Strategy 8: Integrated use of management system standards - IUMSS | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **25** | **52** | **0** | **0** | **21** | **98** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | |
| Total | 25 | 52 | 0 | 0 | 21 | 98 |
| Duplicates between databases | 34 | | | | | 64 |
| Not relevant (First Round) | 10 | | | | | 54 |
| Not relevant Second Round) | 3 | | | | | 51 |
| Not relevant (Third Round) | 47 | | | | | 4 |
| **Final Results** | | | | | | **4** |

Table A19 shows the screening summary applied in search strategy nine.

## Table A19: Screening Summary Search Strategy 9

| Search Strategy 9: OH&SMS and laboratories | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **1** | **8** | **4** | **2** | **0** | **15** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1 | 8 | 4 | 2 | 0 | 15 |
| Duplicates between databases | 5 | | | | | 10 |
| Not relevant (First Round) | 7 | | | | | 3 |
| Not relevant (Second Round) | 0 | | | | | 3 |
| Not relevant (Third Round) | 0 | | | | | 3 |
| **Final Results** | | | | | | **3** |

Table A20 shows the screening summary applied in search strategy ten.

## Table A20: Screening Summary Search Strategy 10

| Search 10: ISO 10001 and ISO 10002 | | | | | | |
|---|---|---|---|---|---|---|
| **Databases:** | **ABI Complete** | **Scopus** | **Web of Science** | **Compendex** | **Emerald Insight** | **Total** |
| **First Results** | **3** | **11** | **6** | **8** | **15** | **43** |
| Duplicates within same database | 0 | 0 | 0 | 0 | 0 | |
| Total | 3 | 11 | 6 | 8 | 15 | 43 |
| Duplicates between databases | 16 | | | | | 27 |
| Not relevant (First Round) | 10 | | | | | 17 |
| Not relevant (Second Round) | 2 | | | | | 15 |
| Already included in other searches | 3 | | | | | 12 |
| Not relevant (Third Round) | 5 | | | | | 7 |
| **Final Results** | | | | | | **7** |

Table A21 shows the screening process summary and final results for all the search strategies.

**Table A21: Screening process summary and final results**

| Search Strategies | Results | Duplicates among databases | Sub-Total | 1st round: Not relevant (based on title) | Sub-Total | 2nd round: Not relevant (based on abstract) | Sub-Total | Duplicates with other searches | Sub-Total | 3rd round: Not relevant (based on whole paper) | Articles used |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 266 | 61 | 205 | 157 | 48 | 25 | 23 | 0 | 23 | 11 | 12 |
| S2 | 67 | 16 | 51 | 16 | 35 | 3 | 32 | 30 | 2 | 2 | 0 |
| S3 | 15 | 5 | 10 | 3 | 7 | 3 | 4 | 1 | 3 | 3 | 0 |
| S4 | 123 | 40 | 83 | 40 | 43 | 21 | 22 | 0 | 22 | 11 | 11 |
| S5 | 206 | 60 | 146 | 60 | 86 | 50 | 36 | 10 | 26 | 18 | 8 |
| S6 | 43 | 11 | 32 | 16 | 16 | 10 | 6 | 0 | 6 | 6 | 0 |
| S7 | 152 | 27 | 125 | 37 | 88 | 32 | 56 | 0 | 56 | 47 | 9 |
| S8 | 98 | 34 | 64 | 10 | 54 | 3 | 51 | 0 | 51 | 47 | 4 |
| S9 | 15 | 5 | 10 | 7 | 3 | 0 | 3 | 0 | 3 | 0 | 3 |
| S10 | 43 | 16 | 27 | 10 | 17 | 2 | 15 | 3 | 12 | 5 | 7 |
| **Sub-Totals** | 1028 | 275 | 753 | 356 | 397 | 149 | 248 | 44 | 204 | 150 | 54 |
| | | | | | | | | | | **Articles used** | 54 |
| | | | | | | | | | | **Snow ball articles used** | 20 |
| | | | | | | | | | | **Theses** | 4 |
| | | | | | | | | | | **Total of sources used** | **78** |

Regarding the papers obtained through snowball, the snowball process is presented in table A22.

Figure A1 shows a graphic representation of the snowball process.

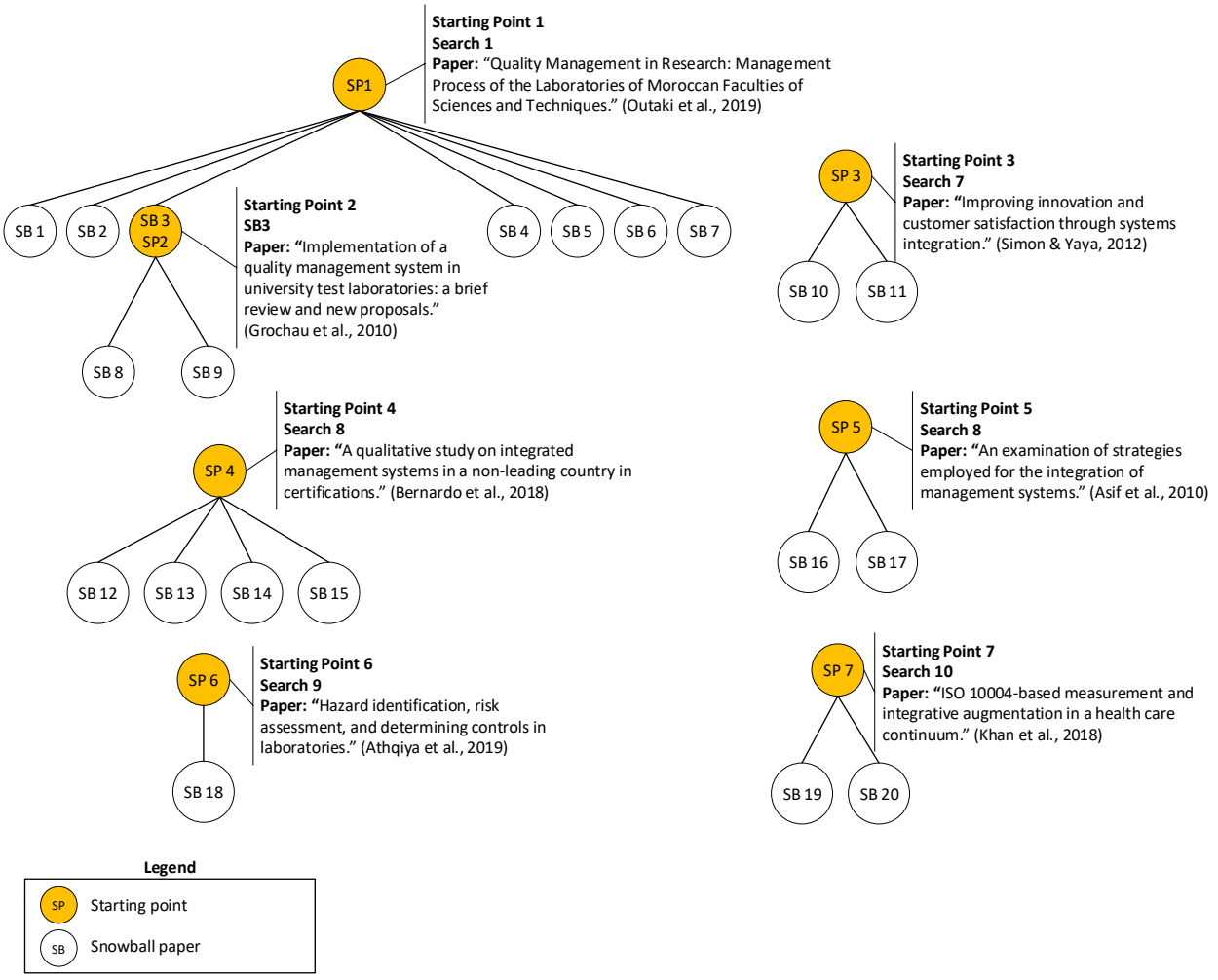
**Table A22: Snowball papers used in the literature review**

| Snowball Paper # | Title | Authors | Literature Review Section | Starting point for the snowball process | |
|---|---|---|---|---|---|
| | | | | Title | Authors |
| 1 | The scope and limitations of a QA system in research | Mathur-De Vré, 2000 | Benefits of implementing QMSs in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 2 | Quality assurance in research and development: an insoluble dilemma? | Krapp, 2001 | Benefits of implementing QMSs in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 3 | Implementation of a quality management system in university test laboratories: a brief review and new proposals | Grochau et al., 2010 | Benefits of implementing QMSs in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |

| Snowball Paper # | Title | Authors | Literature Review Section | Starting point for the snowball process | |
|---|---|---|---|---|---|
| | | | | Title | Authors |
| 4 | Need for quality management in research and development | Cammann & Kleiböhmer, 1998 | Challenges of implementing QMSs in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 5 | Experience of implementing ISO 17025 for the accreditation of a university testing laboratory | Zapata-Garcia et al., 2007 | Challenges of implementing QMSs in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 6 | Quality system implementation in a Brazilian university laboratory | De Nadai Fernandes et al., 2006 | Examples of QMS in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 7 | ISO 17025 quality system in a university environment | Rodima et al., 2005 | Examples of QMS in research laboratories | Quality Management in Research: Management Process of the Laboratories of Moroccan Faculties of Sciences and Techniques | Outaki et al. (2019) |
| 8 | Establishing an ISO 17025 compliant laboratory at a university | Hullihen et al., 2009 | Benefits of implementing QMSs in research laboratories | Implementation of a quality management system in university test laboratories: a brief review and new proposals | Grochau et al., 2010 |
| 9 | On the way to formal accreditation | Vajda et al., 2006 | Examples of QMS in research laboratories | Implementation of a quality management system in university test laboratories: a brief review and new proposals | Grochau et al., 2010 |
| 10 | Integration of quality management and environmental management systems: Similarities and the role of the EFQM model | Tari & Molina-Azorin, 2010 | Basics on integration | Improving innovation and customer satisfaction through systems integration | Simon & Yaya (2012) |
| 11 | Implementing environmental with other standardized management systems: Scope, sequence, time and integration | Karapetrovic & Casadesus, 2009 | Basics on integration | Improving innovation and customer satisfaction through systems integration | Simon & Yaya (2012) |
| 12 | An empirical examination of benefits from implementing integrated management systems (IMS) | Zeng et al., 2011 | Basics on integration | A qualitative study on integrated management systems in a non-leading country in certifications | Bernardo et al., 2018 |
| 13 | Integrated management systems: moving from function to organisation/decision view | Leopoulos et al. (2010) | Integration Methodologies and the IUMSS handbook | A qualitative study on integrated management systems in a non-leading country in certifications | Bernardo et al., 2018 |
| 14 | Benefits of management systems integration: a literature review | Bernardo et al. (2015) | Integration Methodologies and the IUMSS handbook | A qualitative study on integrated management systems in a non-leading country in certifications | Bernardo et al., 2018 |
| 15 | IMS in the M (E) SS with CSCS | Karapetrovic, S. (2005) | Integrative Augmentation | A qualitative study on integrated management systems in a non-leading country in certifications | Bernardo et al., 2018 |

| Snowball Paper # | Title | Authors | Literature Review Section | Starting point for the snowball process | |
|---|---|---|---|---|---|
| | | | | Title | Authors |
| 16 | Integrated management systems: experiences in Italian organizations | Salomone, 2008 | Basics on integration | An examination of strategies employed for the integration of management systems | Asif et al., 2010 |
| 17 | Musings on integrated management systems | Karapetrovic, S. (2003) | Basics on integration | An examination of strategies employed for the integration of management systems | Asif et al., 2010 |
| 18 | Risk at the Educational Laboratory in Indonesia | Qurbasari et al. (2019) | Occupational Health and Safety (OHS) in research laboratories | Hazard identification, risk assessment, and determining controls in laboratories | Athqiya et al. (2019) |
| 19 | Three examples of integrative augmentation in health care and engineering education services | Fernandez-Ruiz et al., 2017 | Integrative Augmentation | ISO 10004-based measurement and integrative augmentation in a health care continuum | Khan et al. (2018) |
| 20 | Implementing an ISO 10001-based promise in inpatients care | Khan & Karapetrovic (2013) | Integrative Augmentation | ISO 10004-based measurement and integrative augmentation in a health care continuum | Khan et al. (2018) |

## Figure A1: Literature review snowball process



# Appendix B: Research methodology

## B.1 Information Letter

**INFORMATION LETTER**

**Study Title:** A Study of the Applicability of Quality, Safety and Customer Satisfaction Standards in Universities Research Laboratories in [redacted].


**Research Investigator:**

Renzo Jaramillo (MSc Student)
Department of Mechanical Engineering
University of Alberta
Edmonton, AB, T6G2R3
Email: [redacted]
Phone: [redacted]

**Supervisor:**

Dr. Stanislav Karapetrovic
Department of Mechanical Engineering
University of Alberta
Edmonton, AB, T6G2R3
Email: [redacted]
Phone: [redacted]


*Background*

You are invited to participate in this study because as a staff member at a research laboratory in the university, you have an advanced knowledge of the processes and expertise in the activities of the laboratory. I am doing this study because I would like to know how applicable specific ISO standards are to university research laboratories' processes and the information that I am getting from you will help me set up process maps and analyze how the standards are applicable to those processes.

*Purpose*

The purpose of this study is to examine the applicability of a Quality Management System Standard (ISO 9001), Occupational Health and Safety Management System Standard (ISO 45001) and Customer Satisfaction Standards (ISO 10001, ISO 10002 and ISO 10004) in the research laboratories of two universities, one in [redacted] and one in [redacted].

*Study Procedures*

This is a qualitative case study, in which I will explore the processes that are carried out in this research laboratory and then analyze the applicability of the Quality, Safety and Customer Satisfaction standards to these processes. I will ask you to provide a brief explanation of the activities that you perform in the laboratory and/or a short illustration of the related laboratory processes. It is anticipated that this will not take more than one hour of your time.

I will ask questions about the processes and the requirements of a particular standard using a questionnaire. All the questions will be related to the processes carried out in this laboratory and the standards requirements. I may also collect information from the documentation that you use or you

provide to me. This information will only be used to generally describe the operation of this research laboratory. Personal information will not be asked.

*Benefits*

You will not benefit from being in this study. I hope that the information I get from doing this study will help to better understand the applicability of the ISO 9001, ISO 10001, ISO 10002, ISO 10004 and ISO 45001 standards and the integration of the systems that follow these standards in university research laboratories.

*Risk*

There may be risks to being in this study that are not known. If I learn anything during the research that may affect your willingness to continue being in the study, I will tell you right away.

*Voluntary Participation*

Participation in this study is completely voluntary. You are not obliged to answer any specific questions even if participating in the study. Even though you have already volunteered, you can still opt out of this study. Even after you have been interviewed, you can ask to change or withdraw any or all of your answers. This can be done anytime up until three weeks after you have been interviewed.

*Confidentiality & Anonymity*

I hope to use the results of this research to produce my MSc thesis. I may also write up the results for submission to journals or presentation at conferences.

To assure the participants' anonymity and confidentiality, during the interview I will not record any personal data that could be used to identify the participant. Personally-identifiable information will not appear in publications. Only the researcher and the supervisor will have access to the data collected.

*Further Information*

If you have any further questions regarding this study, please do not hesitate to contact me or Dr. Stanislav Karapetrovic.

## B.2 Notification Letter - Outside of REB Mandate

**Notification: Outside of REB Mandate**

| | |
|---|---|
| Date: | August 7, 2018 |
| Study ID: | Pro00083219 |
| Principal Investigator: | Renzo Jaramillo Chavez |
| Study Title: | Application of safety, quality and customer satisfaction standards in university research laboratories |
| Study Supervisor | Stanislav Karapetrovic |

Thank you for submitting this application for review. The project as described in this application has been reviewed and it has been determined that this project is outside of the mandate of the Research Ethics Board and does not require or qualify for human ethics review.

Sincerely,

[redacted]
Chair, Research Ethics Board 1

*Note: This correspondence includes an electronic signature (validation and approval via an online system).*

## B.3 Questionnaire

**General Questions about the processes (Planning, Control and Improvement) and ISO 9001**

- Which are the objectives and plans of the laboratories in terms of quality, safety and customer satisfaction? Are they communicated to all the people involved in the work? [clause 6]
- How do you monitor the fulfillment of the plans and objectives? [clause 7]
- What are the services that this laboratory provides? [clause 4]
- Who are the suppliers of the laboratory?[clause 4]
- Who are the laboratory stakeholders (e.g. community, university board, students)? [clause 4]
- What are the types of clients do the laboratory have internally (e.g. students, other university faculties) and externally (e.g. government, companies)? [clause 4]
- How do you know or collect the requirements of each of your internal and external clients and other interested parties? [clause 4]
- How do you know whether you fulfill the requirements that the clients asked for? [clause 9]

- How do you know you fulfill your own quality requirements? [clause 9]
- How do you receive samples for the laboratory? [clause 8]
- Once you receive the customer requirement. How do you plan the different processes for this specific service? [clause 8]
- How do you obtain the resources needed for the performing of the services? [clause 7]
- How do you use the resources needed for the services? [clause 7]
- What are the specific steps that you perform once you receive a customer requirement? [clause 8]
- Is there any documentation (procedures, policies, etc.) that you apply for your work? If so, which are they? How do you manage them? How often do you update them? [clause 7]
- Do you perform internal audits? How? [clause 9]
- How do you manage non-conformities in your work? Do you document any of these actions? [clause 10]
- How do you improve your processes? [clause 10]

**ISO 45001**

- Do you have any document (procedures, policies, etc.) related to safety? If so, which are they?, How do you apply them? [Clause 6, 7]

**ISO 10001**

- Are there any specific commitments that you are making to your customers? [clause 6]

  If so, how do you do that? What do you do about those commitments? What processes do you have to fulfill these commitments? [Clause 7]

  How do you maintain and review your commitments? [Clause 8]

**ISO 10002**

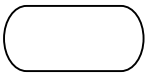
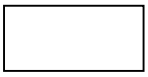
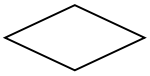
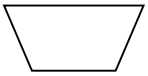
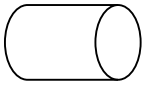
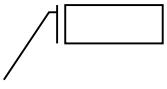
- What happens if there is a problem between the suppliers and/or clients and the laboratory? How do you collect the complaints? How do you handle the complaints? [Clause 7]

**ISO 10004**

- Do you measure clients' satisfaction with respect to the services that the laboratory provides? If so, how do you that? How frequently do you measure your clients' satisfaction? [Clause 6]
- How do you obtain feedback from your clients? [Clause 7]
- How do you incorporate customer feedback into your processes? [Clause 7]

# Appendix C: Flowchart Symbols

**Table C.1 Flowchart symbols**

| Symbol | Description |
|---|---|
|  | Start / End of a process |
|  | Product/Service realization activity |
|  | Input/Output<br>(e.g. customer, complaint or feedback) |
|  | Decision activity |
|  | Document |
|  | Multidocument |
|  | Review activity |
|  | Material or infrastructure resource |
|  | Reference to another part of a process |
|  | Reference to another page |
|  | Comment |