

Defining Functional Requirements for a Dual-Use Compliance Model in Academic Institutions

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Abstract

The regulatory scrutiny surrounding dual-use items, export control and regulatory compliance has increased due to the growing development and use of sensitive and emerging technology in academic research. Academic freedom, research collaboration and institutional autonomy and regulatory frameworks such as the EU Regulations 2021/821, are all important considerations within the complex governance landscape in which universities operate today. Despite this, many of these institutions lack context-specific compliance structures that can address the risks related to intangible technology and dual-use research. This study aims to address this gap by focusing on the systematic development of functional requirements for a compliance model relevant to academic institutions. This study employs a systems engineering methodology incorporating a requirements-driven approach, positioning the functional requirements as an intermediate step in linking the problem identification to the model design. Based on a comprehensive review of existing literature and empirical insights from universities in the EU, UK and Norway through interviews, this study identifies key governance and compliance issues found within institutions. In response, the study formulates a series of fundamental requirements that act as design constraints that shape and outline the model and state the essential features an innovative compliance strategy model should have to support effective management and reporting of dual-use research activities.

Keywords

Functional Requirements, Dual-Use Items, EU Regulations, Compliance and Governance, Systems Engineering

1. Introduction

In recent discourse, the governance of academic research, has been shaped by the increased concerns of modern scientific research. For dual-use research of concern, this is especially relevant as research with potential dual use (knowledge or technology) can potentially be misused, with grave consequences. As hubs of knowledge and information, universities aim to expand their reach. Per the European Union (EU) Parliament (2021), dual-use items in alignment with EU Regulation 2021/821, are defined as “*items, including software and technology, which can be used for both civil and military purpose, and includes items which can be used for the design, development, production or use of nuclear, chemical or biological weapons or their means of delivery, including all items which can be used for both non-explosive uses and assisting in any way in the manufacture of nuclear weapons or the nuclear explosive devices*”. It is per this definition that the EU has established a comprehensive strategy to address and mitigate ethical issues in research, which includes Dual-Use Research of Concern (DURC) (Drew & Mueller-Doblies, 2017). This strategy aims to define responsibilities across stakeholders. Drew and Mueller-Doblies (2017) furthermore state that the European Commission (EC) recognises the need for ethical awareness amongst researchers, claiming that simply expanding ethical outreach is ineffective, and that targeted training at a governmental and institutional level should be proposed instead (National Academic Press, 2017).

As a contingency measure, government agencies and universities have sought after mechanisms and frameworks that aim to address these dual-use concerns, embedded through structures such as ethical committees that aim to assist researchers in preventing possible dual-use related risks of misuse, and guidance frameworks as established by the World Health Organisation (WHO, 2022). Although often fragmented, Bromley (2023) & Frueh and Blatt (2017) states that these mechanisms provide a crucial oversight into the dual-use regulatory structures. This fragmentation includes gaps in holistic and integrated responses to dual-use challenges, inconsistencies in decision making, as well as limited progression to risk identification. Dual-use research and the challenges arising are products of complex social-technical systems in which multiple actors are involved, including stakeholders, processes, and information. Industrial Engineering (IE) techniques, however, allow for the design, integration and optimisation of these complex systems in structured approaches that consider process designs as well as systems and requirements engineering (Ajmal, Islam & Khalid, 2026). DURC, and more importantly, dual-use compliance can be reintroduced as systematic concepts that require defined functions and effective feedback mechanisms. IE principles allow compliance and models associated with compliance to be an important step in the research lifecycle. In the prospect of Requirements Engineering (RE), the process of establishing stakeholder requirements and needs, which are documented to guide whether system development activities, as stated by Tukur, Umar & Hassine (2021), allows system engineers to provide a systematic means of defining what the systems should do to achieve the goal. In the context of dual-use research and dual-use regulations, translating this complex qualitative problem into structured implementable system specifications can assist universities and/or government agencies that are seeking contingency measures to prioritise and mitigate high-risk specifications efficiently.

The main objective of this paper is to define the Functional Requirements (FR), i.e., system specifications, for a proposed dual-use compliance model tailored to academic institutions. The aim is to demonstrate how functional requirements can be systematically derived from a complex and multidisciplinary problem context as opposed to prescribing a fixed or universal compliance framework. By translating the perspectives of stakeholders into thematic elements derived from dual-use challenges and perspectives and the associated literature into collected system requirements or functions, this study furthermore aims to connect the guiding principles to implementation, by positioning the functional requirements between the understanding and design of these system requirements. To achieve this, the paper adopts a qualitative descriptive research approach, as it is the most suitable approach to investigate the complex problem of dual-use compliance in academic institutions and to showcase how functional requirements can be systematically derived. Data has been collected through semi-structured interviews with professional research governance and compliance stakeholders, and this analysis is evaluated through a thematic analysis, highlighting key patterns and recurring themes which will be translated into user-friendly functional requirements to support the eventual development of the compliance model. The contribution of this paper is as follows:

- (i) it advances the understanding of dual-use compliance in academic settings by framing it as an integrated socio-technical systems problem rather than a collection of isolated governance mechanisms.
- (ii) it demonstrates how industrial engineering principles be applied to systematically derive functional requirements in a complex and multidisciplinary context.

- (iii) it illustrates how qualitative insights can be translated into structured system functions through the identification of key intervention points across the research lifecycle, highlighting where and how compliance mechanisms can be effectively embedded.

Together, these contributions provide both a conceptual foundation and a practical basis for the development of more coherent, adaptive, and implementable dual-use compliance models in academic institutions.

2. Methods

For the purpose of this paper, the research approach will follow that of a qualitative descriptive methodology. As we look towards investigating and understanding the complexities of dual-use compliance in academia, as well as understanding the stakeholder perspectives, institutional challenges and governance challenges, the qualitative descriptive approach is appropriate due to its explorative nature (Tenny et al. 2022) as well as the methodology's ability to explain processes and patterns that are quite difficult to quantify. This methodology is represented in Figure 1 below.

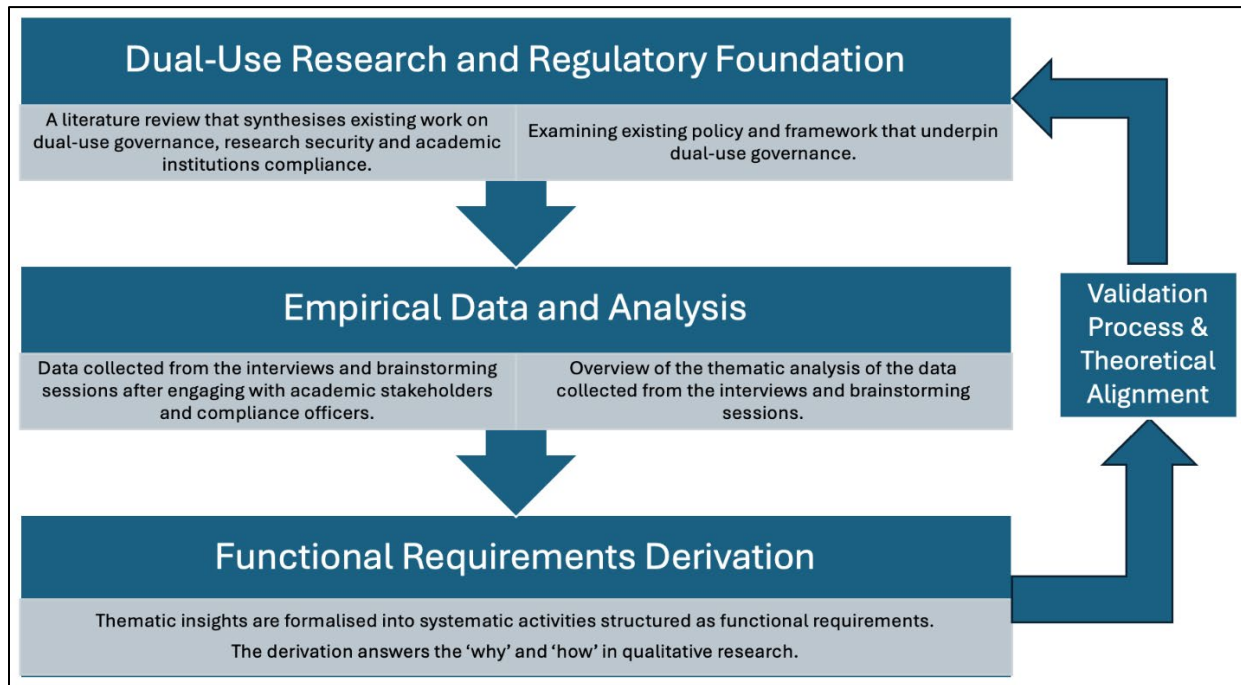


Figure 1: Qualitative Descriptive Methodology

2.1. Dual-Use Research and Regulatory Foundation

Dual-use regulatory frameworks governing research present one of the most complex dilemmas for universities. The complexity arises when knowledge and intellectual property developed in academic contexts can be abused by actors in ways that compromise national security and human rights, and impact ethical responsibility or fair access to innovation. Using the European Union (EU) as a primary case study, the article investigates how EU universities deal with the Dual Use Regulation and associated export control measures. A literature review was undertaken to conceptualise dual-use regulations in the context of the university or academia setting. The aim is to establish a regulatory foundation before delving into empirical data and analysis. Examining the existing literature on dual-use governance and research security, we identify recurring themes in the challenges and perspectives of dual-use regulations.

2.2. Empirical Data and Analysis

Upon completion of the literature review, the study analyses the data collected through semi-structured interviews with research governance and compliance stakeholders across multiple academic institutional contexts. The use of semi-structured interviews facilitates flexible yet contextually responsive exploration of key issues that looks at

capturing both anticipated and unanticipated insights relevant to dual-use compliance. The collected data is analysed using a thematic analysis approach, following an iterative process of familiarisation, initial coding and refinement of theme development. The iterative process enables us to understand why existing frameworks are limited with regard to aspects such as fragmented legislation and challenges in relation to managing intangible technology. The resulting themes capture both institutional dynamics and operational limitations. These themes serve as the framework for the following derivation of functional requirements, acting as a crucial analytical link between qualitative understanding and system-level interpretation. This analysis is generically observed in this paper.

2.3. Functional Requirements Derivation

During this phase of the study, the eight themes identified in the empirical study are methodically interpreted as identifiers of requirements, limitations, and desired capability of the system. Whilst the themes are converted into functional requirements that specify how the compliance model should assess governance issues and efficient decision making, the overall process remains guided by requirements engineering principles, ensuring that stakeholder perspectives and needs are clearly captured and addressed. The intervention points aim to demonstrate where and how the functional requirements operate within institutional processes, enhancing the implementation ability. These functional requirements establish the functional features of an integrated dual-use compliance model.

3. The Evolving Landscape of Dual-Use Research and Governance

The intersection of innovation, security, and regulatory compliance has increased the need to actively address the dual-use risks within academic institutions. Hisham et al. (2025) describe dual-use research as a complex governance system characterised by the ongoing tensions between these competing priorities, as well as by the university-level limitations that academic institutions present. Effective oversight often tends to exist beyond the technical controls and requires increased consideration for all the responsibilities and regulatory requirements; despite the important safeguards these ethical responsibilities provide. Albrycht et al. (2025) add that stronger integration can uplift the strategic importance of dual-use research. Within this, Albrycht et al. (2025) furthermore identified significant barriers and limitations to effective oversight, proposing that a “dual-use-by-design” approach is an applicable contingency method that should be addressed proactively as opposed to retrospectively. Consequently, the problem continues to exist due to intellectual property leakage, difficulties with the protection of data as well as the lack of unclear roles and responsibilities. Whilst the onset of these challenges has reinforced the idea of shared responsibility among various stakeholders, Albrycht et al. (2025) suggest that mitigation efforts need to be thought of holistically as it addresses both technical and organisational considerations.

While Albrycht et al. (2025) argues that increasing geopolitical tensions force governmental agencies and institutions to reevaluate research and innovation models, it is equally important to consider the EU’s need for strategic autonomy, economic security and resilience as reported by Vella (2025). Emerging technology has been proven to serve both civilian and defence purposes, and Vella (2025) reflects on the intensified efforts to strengthen civil-defence synergies within research and innovation ecosystems. Dual-use innovation, however, shares similar contexts to its use in emerging technologies. Stasik (2026) adds that this should not be strictly viewed as a regulatory challenge, but as a contributor to economic growth, social and sustainable development. Initially deemed as the “vision of the future” guided by geopolitics and technological competitiveness, Stasik (2026) claims that dual-use innovation represents a complex interaction between technological advancement and societal needs, as the innovation normally intended to enhance military capabilities can cause a spillover effect into societal development. This interaction gives way for ethical concerns to take precedence, where the potential consequences of misuse can be substantial, however principles of Responsible Research and Innovation (RRI) address these concerns (Stasik, 2026). Supported by a dual-use security study conducted by Ludovici (2021), the RRI aims to promote approaches that include ethical reflection, stakeholder engagement and adaptive governance as a means to continuously consider societal implications rather than stifling innovation or reliance on compliance-based mechanisms.

4. Implications for Dual-Use Governance for Academic Institutions

The growing debate supporting Research and Development (R&D) involving potential dual-use technology is significantly growing due to its potential to strengthen scientific and technological bases, boosting start-ups and SMEs, stimulating innovation, as well as creating new market opportunities (LERU, 2018). While the increasing civil defence synergies create new opportunities in various industrial ecosystems, the distinction between civil and defence R&D remains difficult to establish in practice (EU Commission, 2024). For fundamental research, the application fields are rather unknown compared to medium and high technology readiness levels in R&D, even with technology adaptations

for civil and defence applications. The use of security and defence technology primarily originates in civilian sectors due to higher private sector investments and as technologies mature in the research lifecycles. If given the opportunity, the EU should explore synergies between programmes and instruments to maximise potential for spin-out from these different sectors. The EU Commission (2024) suggests that the main cause of these problems is the “*lack of a common conceptualised definition of dual use items in the context of R&D support, either internationally or at an EU level*”. The EU aims to enhance R&D support for dual-use technology, largely to benefit the European industry and accelerate research and innovation. However, the unpredictable nature of scientific discovery often makes it difficult to determine the possible research outputs (EU Commission, 2024; LERU, 2018). Reinforcing the ‘protect’ and ‘partner’ dimensions, the EU continues to maintain a competitive edge in green and digital transitions by utilising EU-funded R&D projects. We observe that academic institutions are increasingly required to navigate the tension between supporting open research environments and maintaining appropriate security safeguards as a result (EU Commission, 2024).

The challenge of defining academic proliferation is directly linked to the difficulty in defining academic activities. Universities, as a result, now have a full panel of activities often divided into teaching and research, which interact constantly and are not limited to fundamental research only (Charatsis, 2017). Michel (2022) adds that universities have sought out collaborations with industry to produce applied research programs that offer consulting services to stakeholders as well. These research facilities and universities may also now be involved in motives that seem to be comparable to those in industry. As such, universities can no longer be limited to fundamental science, so defining academic proliferations’ specificity should be narrowed to include research activities and objectives (technical assistance). Unlike industrial manufacturers, universities rarely produce physical dual-use items. Their primary outputs are knowledge, technical expertise, software, data, and research findings, which are typically transferred in intangible forms. Consequently, Charatsis (2017) suggest that the risk for transferring an item listed in the legislative frameworks or by the EU Common Military is rather low, further explaining that the situation is rather complex for dual-use items (Charatis, 2017; LERU, 2018).

The literature identified two main difficulties in controlling dual-use items faced by academic institutions. The first instance refers to the awareness and understanding of export control obligations. Many researchers remain unfamiliar with the extent to which some activities may fall under trade control legislation and require authorisation from public authorities, often perceiving such requirements as an infringement on academic freedom, as most academics believe their research objectives are not related to prohibited activities (Michel, 2022). The second instance refers to the identification and classification of dual-use items. Michel (2022) reported that the difficulty that researchers experience in identifying whether the item is listed in the Annex I of the EU Dual Use Regulation remains prominent. Academics typically transfer technology in an intangible form, and subcategories of the controlled list may not match the description of activities and items involved in their research. For example, a researcher in the EU has access to a virtual listed item for a virtual resistance test, but the transfer to their counterparts in a third country is not the item or technology but a set of data resulting from the test (Michel, 2022). Historically, academia and research institutions do not have a tradition of implementing trade control measures compared to industries and organisations. Many institutions have been confronted only recently with the necessity of implementing trade control rules even if, in principle, their activities were not exempted from the regulation. While universities increasingly recognise the importance of managing dual-use risks, some researchers have been reluctant to accept the right of export control authorities to control their cooperation or collaboration activities. However, since the recast of the EU Dual Use Regulation, that have now included academia and research institutions as part of its scope, they are required to accept and implement some controls on their activities. The difficulty is precisely to define which ones will require authorisation and which will be exempted (Charatsis, 2017).

5. Empirical Evidence: Thematic Insights into Dual-Use Compliance

The governance of dual-use research within academic institutions is characterised by the level of complexity, uncertainty and understanding of dual-use regulations and dual-use research. In particular, the practical implementation remains quite challenging within research-intensive environments despite the existence of regulatory frameworks to manage the exchange of sensitive goods and knowledge. These frameworks, rarely a matter of identifying controlled items, require tedious navigation processes in an already ambiguous framework. This excludes the evolving technological developments, competing organisational priorities and resource constraints that universities collectively experience. From the interviews conducted with universities across from the Netherlands, Belgium, Norway and England (sampling of $n = 8$), a recurring challenge that all institutions face, is the issue of identifying and classifying (application) dual use items, as unlike with traditional export regulations that only work with tangible

goods, the dual-use regulation does not account for the use of intangible goods, which is commonly found in academic environments. As a result, determining whether intangible forms of technology and goods, such as technical assistance, research outputs and publications, as well as data sharing, fall within the scope of regulatory requirements can be a difficult task, in particular in instances where emerging technology and multidisciplinary research are involved.

Uncertainty remains at the forefront as universities aim to distinguish between fundamental and applied research, since many projects are explorative in nature and predicting the outcome and to what extent the knowledge and technology may eventually become applied research. This uncertainty is especially important as evolving fields of study may generate both socially beneficial outcomes in research as well as mistakenly creating opportunities for unintended consequences. Complexity extends beyond compliance obligations as export control regulations additionally incorporate considerations into intangible goods and end-user assessment. This adjustment, therefore, requires researchers and universities to make calculated guesses or judgment calls, as complicated and a lack of clear guidance poses extra risk of non-compliance. The expectation of universities to promote academic openness while protecting sensitive technology and knowledge presents not only an issue for universities but for environments, often governmental agencies, where collaborative research environments account for information and expertise to be routinely shared across institutional and disciplinary boundaries. Therefore, it is agreed that academic freedom should, as far as possible, be maintained to enable informed decision-making and managing effective risk management with external stakeholders. The problems of dual use compliance are not solely from regulatory circumstances but also organisational and societal contexts. It is through this understanding that the need for integrated approaches in supporting the identification, decision-making and oversight is critical. Per the thematic analysis conducted, the following eight main themes emerged from the interview questions. These themes explore the challenges contextually and provide an empirical basis for the subsequent derivation of the functional requirements of a compliance model. Table 1 below captures these eight themes and the number of occurrences within the thematic review.

Table 1: Quantifying Thematic Data

#	Established Theme Name	Number of Occurrences
1	Academic Freedom Concerns	215
2	Collaboration and External Engagement	227
3	Education and Training	50
4	Emerging Technologies and Adaptive Governance	68
5	Geopolitics and Contextual Factors	91
6	Institutional Governance and Responsibility	72
7	Regulatory and Compliance Challenges	232
8	Risk and Ethical Dilemmas	252

In Table 1 above, from the eight universities dispersed across UK and Europe that were interviewed, a total of 1207 coded occurrences were established. The most prominent theme was **Risk and Ethical Dilemmas**, closely followed by **Regulatory and Compliance Challenges**, **Collaboration and External Engagement** and **Academic Freedom Concerns**. These four categories collectively constitute (approx.) 76.7% of the total coded dataset. This vast concentration suggests that the most predominant discussions with participants were focused on the tensions between risk management, compliance and regulations, external and internal collaboration in a research context, as well as the preservation of academic freedom at universities. The bottom four themes were comparatively less prominent but nonetheless provided important contextual insights for the most prominent themes. The least frequently cited theme was **Education and Training**; however, despite this low representation, this theme presents a significant role in enabling and highlighting contextual factors that may heavily influence the institutions' responses. The distribution demonstrates a strong emphasis on urgent governance and compliance as well as risk-related concerns, whilst topics that are linked to institutional competence building, organisational learning and adaptive governance received comparably less attention. This trend shows that rather than the enabling mechanism needed for long-term capability development, participants were more focused on the operational and strategic difficulties involved in managing dual-use risks. While the frequency or number of coding occurrences details an indication of the prominence of themes within the dataset, in a holistic sense, this does not represent a direct measure of participant perspectives. The

researcher's interpretation was engaged in the coding, categorisation and aggregation of themes, therefore, the final tallies of the number of coded occurrences are somewhat impacted by analytical judgment. Rather than being statistically independent indicators, the given frequencies should be interpreted as a sign of thematic importance within the analytical framework. Coding choices were used uniformly throughout the dataset to reduce potential bias, justified by the literature, and themes were continuously improved to guarantee congruence between the data and the generated thematic groupings.

5.1. Academic Freedom Concerns

The results highlight how academic freedom and the increasing demands of dual-use governance and regulatory compliance are intricately related. Participants constantly emphasised the necessity to protect research and institutional autonomy whilst also acknowledging the significance of preventing the misuse of research products. Universities are continuously expected to compromise between requirements resulting from export control legislation and larger research security considerations, with scientific openness and knowledge sharing included in this. Most noticeably, we observe tensions arising from this complex balancing act between maintaining academic freedom and ensuring that regulations intended to preserve national and international security are followed. Determining when research activities fall under the purview of dual-use regulations remained a persistent issue. When future application, end-users and downstream effects are unknown, researchers frequently resort to basic research, or in the worst-case scenario, completely halted their research. Given the lengthy time spans involved in publication and technology advancement, participants pointed out that institutions are forced to deal with circumstances in which knowledge produced for justifiable academic reasons could subsequently be used in unexpected contexts. The intangible factor of many research outputs, which do not fit into the conventional regulatory classification, adds to this ambiguity. Consistency and accessibility to regulatory guidance were additional concerns reported. While some universities benefited from cooperative ties, others experienced trouble getting timely feedback. Guidance mechanisms were thought to be crucial for helping researchers understand complicated rules and ensure that compliance requirements don't needlessly impede acceptable research activities. The concluding remark cited by participants emphasised that dual-use governance is more than just a compliance exercise but rather an advocacy for responsible researchers being more aware of their work.

5.2. Collaboration and External Engagement

Collaboration and external engagement represent a significant area of concern within dual-use governance, as universities take part in multi-disciplinary projects and international knowledge exchange initiatives. It remains crucial to manage partnerships in a way that promotes scientific progress and advancement while guaranteeing adherence to export control and the dual-use regulation. In similar contexts, institutions are required to manage connections within government agencies and industry partners, all of which operate under dynamic regulatory settings. The need to strike a balance between academic openness and suitable safeguards has emerged as research is projected to become more globalised. Prominent shared responsibility between researchers and universities represents a step towards due diligence proceedings, whilst forming partnerships is expected to be normalised to ensure that cooperative activities aren't being non-compliant. Important safeguards were often identified in existing governance systems, such as risk-screening procedures, partnership assessments and ethical review committees. Many participants pointed out that these procedures are not always adequately integrated or uniformly applied across institutions – ultimately, leaving room for uncertainty about how collaborations presently should be evaluated. Limited institutional capacity has greatly impeded effective collaboration management efforts, as comparatively small compliance teams make assessing all research efforts for possible dual-use implications effectively challenging. As a contingency measure, many universities have resorted to increasing awareness campaigns, enforcing training programs, included useful guidelines in course content to aid researchers at every stage of cooperative projects, discussed later in the Education and Training sub-section. Where dual-use governance is a relatively new area of responsibility, strengthening existing institutional expertise became increasingly important. Although lacking and circumstantially not viable, governmental agencies have provided limited support to facilitate greater interaction between universities and regulatory bodies. However, reported concerns highlight administrative burdens, lengthy approval processes and inadequate access to regulatory guidance as factors that limit the need to utilise governmental agencies.

5.3. Education and Training

Education and training, the least coded theme as per Table 1, is an essential component to mitigate many issues present in dual-use governance. Dual-use research, export control laws and the wider implications of knowledge security still remain a foreign concept to many researchers, despite the high level of technical proficiency in their fields, but as we observe, there is often little knowledge of how their work could be affected by regulations or have unforeseen

implications. Resulting observations show that universities are privy to how important dual-use guidelines are to researchers as they need to comprehend the opportunities and obligations that can come with their research. Ongoing investments in training programs and workshops are being applied to institutions that continue to face difficulty with the highly technical, complex language of these regulations. Postgraduate programs have also incorporated information on dual-use risk, research ethics, and responsible innovation early in the academic lifecycle as a starting point to successfully promote a culture of accountability and awareness from the start of their academic journey. Such programs allow institutions to encourage researchers to think about the wider consequences of their work throughout the research process rather than just when compliance issues come up. These programs are advised to be continuous processes that call for frequent participation and opportunities for engagement rather than a one-time intervention.

5.4. Emerging Technologies and Adaptive Governance

Emerging technologies are ongoing and advancing developments whose consequences, hazards, and uses are not yet completely recognised or sufficiently addressed by the governing frameworks currently in place. Determining how new technologies should be categorised and evaluated from a dual-use perspective poses a challenge for academic institutions. Especially noticeable in research settings where technology changes quickly and where potential uses might not be immediately clear in the early phases of development, the governance of emerging technology is particularly difficult in situations where researchers who usually create technologies with positive goals in mind aren't mindful of the advancement of these technologies, nor how accessible these technologies become to many users. Advanced computing, artificial intelligence, data analytics, and quantum-related research were often mentioned as examples of technologies that have the potential to both provide opportunities for destructive or unintentional use and produces enormous societal advantages. The uncertainty, in which researchers and institutions are frequently forced to make decisions about possible future dangers without having full knowledge of how technologies may be utilised, makes compliance efforts more difficult as traditional regulatory processes were often thought to be built on established technologies and well-defined categories. Participants observed that the rapid pace of technology development can result in circumstances in which regulatory frameworks fall behind innovation, raising questions about relevant controls, compliance requirements, and oversight duties. Rather than depending on basic regulatory definitions, institutions sought after systems that are able to adjust to changing technology landscapes. To guarantee early recognition throughout the research lifecycle, several participants believed that continuous evaluation and monitoring of research activities proved to mitigate the overarching problems.

5.5. Geopolitics and Contextual Factors

In a geopolitical climate, universities must function in circumstances where scientific cooperation, national interests and regulatory expectations collide, as research security progresses under the influence of broader geopolitical trends. Most participants emphasised that while universities should continue to be sensitive to national security concerns, they should also be able to make institution-specific and educated decisions about research collaborations. Many perceive government guidance would be helpful, especially when it clarified new hazards and legal requirements; however, methods that facilitate well-informed institutional decision-making were preferred over prescriptive supervision. Collaborations often occur where academic procedures meet security and legal concerns, where, in these instances, ambiguity within the regulations, such as misinterpretations, took precedence. Decisions regarding recruiting students or researchers from foreign countries, student mobility, and researcher access to sensitive research environments have also been demonstrated to be influenced by geopolitical factors. When interacting with people, partners, or organisations functioning in higher-risk geopolitical contexts, participants detailed instances in which extra due diligence procedures were carried out. These instances were typically presented as attempts to control research security concerns while upholding pledges to international cooperation and transparency.

5.6. Institutional Governance and Responsibility

In contrast to having a task that can be delegated to a single person or department, effective dual-use governance was often characterised as a shared institutional responsibility. Participants pointed out that many compliance decisions necessitate access to expertise that goes beyond individual researchers, even if principal investigators are nonetheless responsible for their research activities. Legislative views are frequently required on emerging technology. Many universities have created cross-functional committees and advisory structures as an added contingency measure. Regulatory duties may not always become immediately apparent; however, various means to assess research work, discuss ambiguous issues, and support decision-making were established to lessen the workload for individual researchers and encourage more uniform institutional solutions to dual-use issues. Many universities rely on staff who do governance-related tasks in addition to other duties, rather than having specialised compliance teams as a result of resource limitations. This ultimately makes it challenging to maintain training programs, awareness campaigns, or

thorough project evaluations. Rather than just continuously implementing regulations, governance was often linked to fostering a culture of responsible research, where participants identified stakeholder engagement activities and awareness campaigns as crucial tools for enhancing institutional comprehension of dual-use issues.

5.7. Regulatory and Compliance Challenges

Export regulations have been in place for several years, but public awareness of these regulations has significantly increased over the past two years. For some universities, the regulatory framework aims for a general set of laws complemented by more specific regulations, particularly aligned with EU standards. This alignment includes a list of regulated or prohibited items based on international guidelines, facilitating stability and less frequent changes in regulations. These universities typically don't have trouble identifying physical items subject to export control, as these items are clearly listed. However, for others, classifying non-physical items, such as technological knowledge, presents more challenges. Initiatives have been launched to enhance awareness and streamline processes around knowledge security, with the aid of tools. Online tools, such as the Dual-Use Goods Checker developed for UK institutions and government agencies, can assist researchers with classification tasks, as it recognises that researchers are the experts in their fields and can benefit from a system that streamlines the classification process. In one instance, a research security committee are being formed and incorporated in routine activities, which will include representatives from various faculties and will focus on high-level discussions and policy implications. This committee aims to handle cases that may arise and influence future policies.

5.8. Risk and Ethical Dilemma

Building on the primary theme, a number of supporting themes are evaluated to elucidate the various dimensions of risk and ethical challenges present in the data. Risk and ethical dilemmas revolve around the ethical considerations and due diligence processes that universities undertake when partnering with universities involved in sensitive and/or dual-use technologies. At the outset, it should be understood that there are specific considerations when legitimate export control licenses are applied for in terms of controlled goods, and access to or the transfer of such controlled goods is done under specific contractual and legal obligations for all parties involved. On the other hand, there are specific considerations to prevent the unintended access to or transfer of these sensitive technologies and/or dual-use technologies and items to organisations in countries, which are called "countries of concern". These specific concerns are usually included in more than one sanction list as reported participants, to identify and exclude partners involved in harmful activities from obtaining access to sensitive or dual-use technologies. There are specific partners and companies in high-risk environments that may potentially use sensitive technologies in repressive ways. The universities are advised to be careful about preventing unintended damages caused by their research, especially when considering potential collaboration with partners from high-risk countries due to geopolitical and human rights violation concerns. Some institutions have committees that decide whether the potential partner is acceptable based on their internal criteria and legislative requirements. They prioritise the risk of potential misuse of research findings and outcomes and the partners' ethical standing over individual project assessments.

6. Functional Requirements Derivation

The thematic empirical evidence provides the foundation for the derivation of functional requirements. By identifying the institutional challenges, needs and governance gaps associated with dual-use compliance within academic environments, the functional requirements can be derived. The purpose of this section is to demonstrate how Industrial Engineering principles can translate the thematic findings into a structured set of functional requirements. The order of operations is represented in a matrix in Figure 2 below:

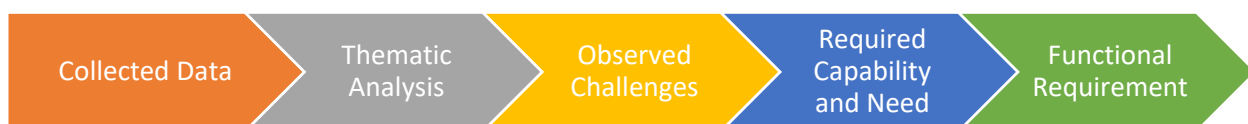


Figure 2: Derivation Process

The functional requirements derivation process encompasses large portions of a Requirements Traceability Matrix (RTM), which is defined by Fries & Bloesch (2004) as a document or a figure that maps and links functional requirements from their origin to the final deliverables, with its primary purpose to ensure that all objectives are met and verified thoroughly. Hence, to record the process of deriving functional requirements from thematic findings, the traceability matrix was developed. The matrix offered a structured method for converting qualitative data into practical

requirements for a dual-use compliance model by connecting identified obstacles and stakeholders' needs to specific systems capabilities from a systems engineering perspective. The **required capability and need** can be established by adapting Table 1 to measures of Importance and Urgency, as can be seen in Table 2 below.

Table 2: Traceability Matrix adapted to include Prioritization Matrix

Theme Concerns	Primary Challenge	Required Capability	Matrix		FR ID
			Importance	Urgency	
Academic Freedom	Finding the balance between academic autonomy and compliance.	Additional assistance and guidance in decision making.	4	4	01
Collaboration and Engagement	Managing risks associated with high-risk countries.	Effectively managing collaboration and partnerships.	4	3	02
Education and Training	Lack of awareness, training, and guidance.	Incorporation of training and awareness programmes.	3	4	03
Emerging Technologies	Difficult to regulate and assess.	Risk assessments and monitoring with stifling innovation.	2	3	04
Geopolitical Factors	Managing factors influenced by geopolitical tensions.	Due diligence procedures	3	2	05
Institutional Governance and Responsibility	Fragmented responsibilities and governmental assistance.	Government involvement and oversight.	3	3	06
Regulatory Challenges	Unclear and complex regulation interpretations.	Tools and strategies for regulatory and compliance refinement.	5	4	07
Risk and Ethical Dilemma	Unintended consequences of unintended misuse of items.	Risk evaluation and methodologies	5	5	08

The prioritisation matrix metrics form the basis of determining an overall risk classification (low, high, medium). We define **Importance** in this instance as the extent to which a capability contributes to addressing the identified institutional challenges, while **Urgency** reflects the rate of need or time sensitivity associated with implementing that capability. These identified factors make it possible to prioritise the needs in a structured manner and facilitate the critical and supplementary system functions. Before the functional requirements table is showcased, the resultant risk levels are visually represented in Figure 3 below, which will guide the development of the functional requirements. We observe from the graph in Figure 3 that the relationship between the various metrics is as follows:

↑ Importance & ↑ Urgency Yields ↑ Risk

The general trend in Figure 3 signifies that many of the themes developed from the data collection are medium to high-risk themes, with an Importance score of greater than 3 and an Urgency score of greater than 3 as well.

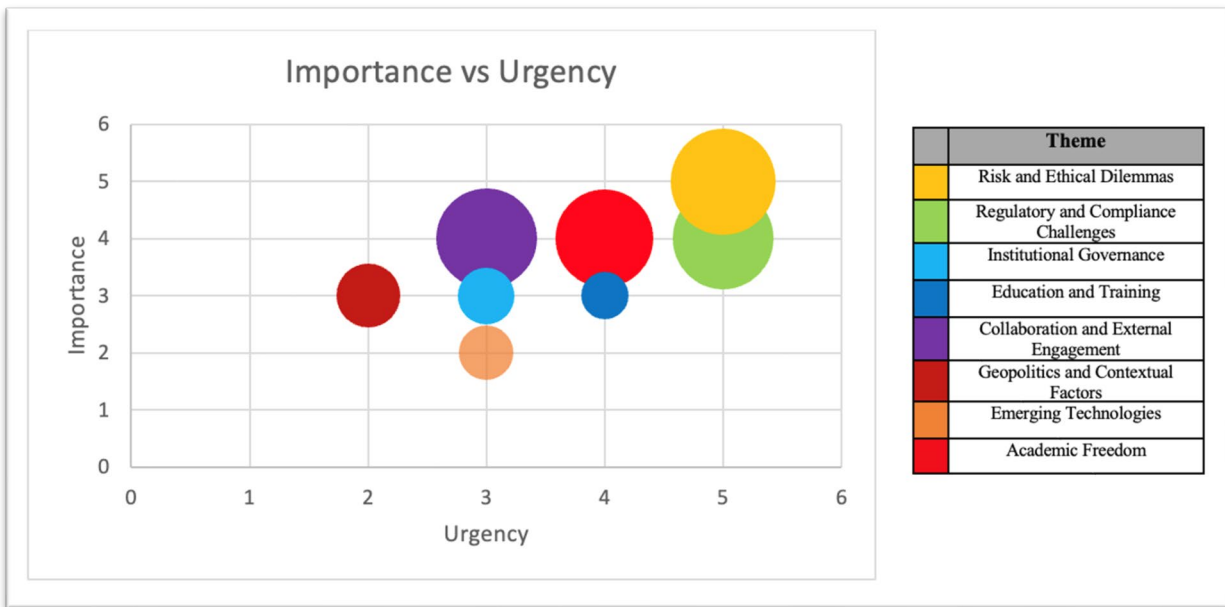


Figure 3: Importance-Urgency Matrix

The analytical interpretation derived from the graph prompted focus toward the (i) prominence of the theme, (ii) potential impact on dual-use compliance, and (iii) the urgency of required intervention. These three factors were validated by informal brainstorming and benchmarking discussions, although some subjectivity was involved. The traceability matrix, in Table 2, as well as the bubble prioritisation matrix, in Figure 3, establishes the identified challenges and was subsequently formalised as functional requirements as summarised in Table 3.

Table 3: Functional Requirements for the Dual-Use Compliance Model

FR ID	Functional Requirements	Risk Level
FR-01	The system must provide guidance and assistance to researchers with the use of tools and assessments to maintain academic freedom.	HIGH
FR-02	The system must support risk-based assessments and a review analysis of potential partnerships and collaborators.	HIGH
FR-03	The system must offer training programs and context-sensitive awareness regarding responsible research practices and export control procedures to prevent potential non-compliance.	MEDIUM
FR-04	The identification and evaluation of new technologies must support and mitigate the potential for dual-use without stifling innovation completely.	LOW
FR-05	Contextual due diligence procedures pertaining to end-user should be incorporated and made easier to facilitate by the system.	MEDIUM
FR-06	The system should advise on the facilitation of government involvement for the purpose of framework decision-making, as well as developing structures to streamline communication and make access easier.	MEDIUM
FR-07	The system must facilitate an ease of interpretation with regard to the identification and classification of dual-use items, differentiating between intangible and tangible items.	HIGH
FR-08	The use of risk-based assessments must constitute ethical and risk evaluation procedures of the research activities to identify potential areas of misuse or non-compliance.	HIGH

From Table 3 above, we observe that the derived functional requirements can effectively facilitate and necessitate a dual-use compliance model that extends regulatory adherence and incorporates aspects of governance, assessment, and awareness of support capabilities. The various levels of risk reflect the priorities of the capabilities identified in the derivation process. The capabilities assist in determining where resources and interventions require immediate

attention or could benefit from intervention over a longer period of time. A **High-Risk** classification refers to compliance activities with both a high level of importance and urgency in the compliance model. These requirements are generally considered foundational in dual-use governance and include required capabilities such as regulatory assessments and ethical risk evaluations. Should institutions fail to address these risks, they could be subjected to continuous non-compliance issues as well as possible exposure to regulatory and reputational risks. A **Medium-Risk** classification enables capabilities that may not require the same extent of urgency but are still essential to the model's overall efficacy. These requirements typically enable processes that strengthen the compliance environment and include capabilities such as in education and training programs as well as due diligence procedures. The long-term stability and maturity of the compliance model are significantly improved by addressing these shortcomings, even though medium risk capabilities may not cause immediate compliance issues. A **Low-Risk** classification refers to capabilities that act as supportive requirements. Despite the lower prioritisation, the long-term effect of these capabilities remains highly important. These requirements, guided by industrial engineering practices, form the foundation of the capabilities needed for a compliance model that can efficiently assist and support academic environments.

7. Conclusion

Guided by existing literature and through interviews with universities, we observed that academic institutions operating in complex research and regulatory environments continue to be subjected to the consequences of unintentional non-compliance. As a result of significant challenges faced in the governance of dual-use items, a few mitigation efforts have been established aside from export controls and responsible innovation practices. This study aimed to address this gap by focusing on the systematic development of functional requirements for a compliance model relevant to academic institutions. This was done by investigating the perspectives on dual-use compliance in the literature as well as through empirical evidence. Eight themes emerged by applying thematic analysis to the data collected, highlighting the challenges experienced by research governance and compliance stakeholders. These themes were interpreted from a systems engineering perspective to derive functional requirements capable of supporting a potential dual-use compliance model. The results of the derived functional requirements showcase how Industrial Engineering principles and systems-oriented approaches can translate qualitative evidence into useful institutional capabilities established by the link between thematic findings and system-level requirements.

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