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A data-driven approach for a project management methodology for R&D Projects

by

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"Caminante, son tus huellas el camino, y nada más;
Caminante, no hay camino: se hace camino al andar.
Al andar se hace el camino, y al volver la vista atrás
se ve la senda que nunca se ha de volver a pisar,
Caminante, no hay camino, sino estelas en la mar."

Antonio Machado

Acknowledgments.

Gloria, I still remember the night it all happened, the music playing in the background on one of the few electrical appliances we had. Sitting on the floor by the window and hugging each other, while watching how Bogotá was giving us one of its magical nights, where the cloud of pollution gave way to a starry night and a red moon at dusk. [1]

I remember your story, your dreams, your question; I remember every single second that passed while I was thinking, even though I had already made up my mind from the moment your story began. I remember the emotion, I remember the fear, I remember the love, I will never forget the love, and at this moment, I can't help but feel proud of you, of me and of the decision we made because of that moment on our life changed completely. So that gift you gave me changed my whole life [2].

I wonder if it was bravery or stupidity, and I still cannot answer myself. You know that I don't consider myself a particularly brave or notoriously stupid person (at least according to the definition of the great Carlo M. Cipolla [1]. Despite the tireless effort I make night after night to prove you otherwise; we have been able to walk this path together. Hard, and as hard as it can be, challenging day after day, complex as we would never have thought, but exciting beyond compare. That is why the satisfaction it gives me to finish this road and to be able to move forward to set new goals, new places, new learning, new paths, and new lives.

That is why I thank you, Mamor, especially you, but also all the people who were there in one way or another. Tatiana Pineda, my tutor, friend, advisor and a big part of my everything. Sara Sendino, for her company and guidance from day one. Unai López-Novoa, for all the timely advice and guidance in the moments when I needed it the most. Santiago Gálvis, "Mi Perrito", for the closeness and remembrance. Nargiza Mikhridinova, of course, the example, the dedication and her openness that I needed to learn so much. Bertha Ngereja who is the most positive human being I have ever had the pleasure of meeting. Carsten Wolff, one of the most brilliant human beings I have ever met, for his teachings, support and kindness. Iñigo Santisteban, the best friend we could have wished for. Itziar Garrote and Octavio Pereira, for their example, education, conversations, tenacity and time. Aitor Irazabal, Jon Ander Iturrioz and Olatz Parola, without whom, without a doubt, the day-to-day life would have been much harder to bear.

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[1] Cerati, G., Bosio, Z. (1992). Luna Roja - Dynamo [CD]. Argentina: Sony Music.
[2] Jorge Drexler (2017). Pongamos que hablo de Martínez - Salvavidas de hielo [CD]. España: Warner Music

Thanks also to every member of the CFAA, a place that has been my second home for the last five years, where I have been allowed to learn, make mistakes, pick myself up whenever I need to, and feel an essential part of it.

Finally, I have always thought that one never walks alone, but that every step we take with us, carrying with us each and every one of the people who have been part of our history. So, of course, my family in Colombia, my parents, brothers, sisters, aunts, cousins, and friends. I carry each and every one of you with me every step of the way, and I am what I am because of what you allowed me to learn from all of you. I also thank those I consider my friends from the bus stop: Andrés, Nagore, Esti, Javi, Javier, and Silvia, who have allowed us to feel part of each other and to raise our daughter in a community.

And you are still too young to read and understand this, Maite, but in time I hope you will know that this is also for you; of course, it is for you. You are my life, love, and desire to live and move forward, achieve goals, and improve myself daily. So THANK YOU, with capital letters, because my heart is completely whole for you. Because I have felt things that I didn't even know existed and didn't think I deserved, for filling me with pride every day for being your father and feeling enormously grateful for having the privilege of seeing you grow day by day. I love you beyond measure.

To all of you and those I have unfortunately not mentioned here, as the greatest said, "Gracias, totales".

Gloria, aún recuerdo la noche en que todo ocurrió, la música sonando de fondo en uno de los pocos electrodomésticos que teníamos, sentados en el suelo junto a la ventana y abrazados viendo como Bogotá nos regalaba una de sus noches mágicas, donde al anochecer, la nube de contaminación daba paso a una noche estrellada y a una luna roja [3]*.*

Recuerdo tu historia, recuerdo tus sueños, recuerdo tu pregunta, recuerdo cada uno de los segundos que pasaron mientras pensaba; aunque ya me había decidido desde el momento en que comenzó tu narración. Recuerdo la emoción, recuerdo el miedo, recuerdo el amor, nunca olvidaré el amor, y en este momento no puedo evitar sentirme orgulloso de ti, de mí y de la decisión que tomamos, porque desde ese momento nuestra vida cambió por completo. Ese regalo que me diste cambió mi vida entera [4]*.*

Me pregunto si fue valentía o estupidez, y todavía no soy capaz de responderme. Sabes que no me considero una persona especialmente valiente ni notoriamente estúpida (al menos según la definición del gran Carlo M. Cipolla [1], y a pesar del esfuerzo inagotable que hago noche tras noche para demostrarte lo contrario); pero gracias a ello hemos podido recorrer juntos este camino. Duro, y tan duro como puede ser, desafiante día tras día, complejo como nunca hubiéramos pensado, pero emocionante sin comparación. Por eso, la satisfacción que me da terminar este camino y poder avanzar para plantear nuevas metas, nuevos lugares, nuevos aprendizajes, nuevos caminos, nuevas vidas.

Por eso te doy las gracias. mamor, especialmente a tí, pero también a todas las personas que estuvieron ahí de una u otra manera. Tatiana Pineda, mi tutora, mi amiga, mi consejera y una gran parte de mi todo. Sara Sendino, por su compañía y guía desde el primer día. Unai López-Novoa, por todos los consejos oportunos y la orientación en los momentos en que más lo necesitaba. Santiago Gálvis, "Mi perrito", por la cercanía y el recuerdo. Nargiza Mikhridinova, por supuesto, el ejemplo, la dedicación y su franqueza que tanto necesito aprender. Bertha Ngereja, el ser humano más positivo que he tenido el placer de conocer en la vida. Carsten Wolff, uno de los seres humanos más brillantes que he conocido en toda mi vida, por sus enseñanzas, su apoyo y su amabilidad. Iñigo Santisteban, el mejor amigo que hemos podido desear. A Itziar Garrote y a Octavio Pereira, por su ejemplo, enseñanzas, conversaciones, tesón y tiempo. A Aitor Irazabal, Jon Ander Iturrioz y Olatz Parola, sin los cuales, sin duda, el día a día hubiera sido mucho más difícil de aguantar.

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Gracias también a todos y cada uno de los miembros de la CFAA, un lugar que ha sido mi segundo hogar durante los últimos 5 años, donde me han permitido aprender,

[3] Cerati, G., Bosio, Z. (1992). Luna Roja - Dynamo [CD]. Argentina: Sony Music

[4] Jorge Drexler (2017). Pongamos que hablo de Martínez - Salvavidas de hielo [CD]. España: Warner Music

equivocarme y levantarme cada vez que lo necesitaba, y sentirme una pieza importante de allí.

Por último, siempre he pensado que uno nunca camina solo, sino que cada paso que damos lo hacemos llevando con nosotros a todas y cada una de las personas que han formado parte de nuestra historia. Así que, por supuesto, mi familia en Colombia, mis padres, mis hermanos y hermanas, mis tías, mis primos, mis amigos. A todos y cada uno de ustedes los llevo conmigo en cada paso del camino, y soy lo que soy gracias a lo que me permitieron aprender de todos ustedes. También agradezco a los que considero mis amigos de la parada del autobús, Andrés, Nagore, Esti, Javi, Javier, Silvia, que nos han permitido sentirnos parte y criar a nuestra hija en comunidad.

Y tú eres aún demasiado joven para leer y entender estas palabras, Maite, pero con el tiempo espero que sepas que esto también es para ti, por supuesto que es para ti. Tú eres mi vida, mi amor, mis ganas de vivir y avanzar, de alcanzar metas y de superarme cada día. Así que GRACIAS, con mayúsculas, porque por ti mi corazón está completamente lleno, porque he sentido cosas que ni siquiera sabía que existían y que no creía merecer, por llenarme de orgullo cada día por ser tu padre y sentirme enormemente agradecido por tener el privilegio de verte crecer día a día. Te quiero sin medida.

A todos ustedes y a los que lamentablemente no he mencionado aquí, como dijo el más grande, "Gracias, totales".

Abstract

Research and Development (R&D) projects are fraught with significant problems, such as the likelihood of failure, the high rate of projects ending without results, the changing project scope, the prolonged project life cycle, and the clash between the interests of academics and companies. Furthermore, R&D projects are also characterised by the difficulty of bounding to defined periods and planning. The non-fixed scope of these projects can change due to internal and external factors. Besides that, the Technology Readiness Level (TRL) in which the R&D project is conducted determine its characteristics and challenges. Furthermore, the quality of the result of an R&D project is seen only at the end of it. This result is formed by the progressive and cumulative realisation of the activities that make it up. It also depends on several features, characteristics and attributes that contribute to meeting the needs and expectations of the stakeholders.

The main goal of this thesis is to overcome some of the issues inherent to these types of projects, developing a project management methodology based on Earned Quality Method (EQM) and data analysis to improve the efficiency of R&D projects in a near-real production environment in a TRL 5-7.

The thesis relies upon published papers that propose measuring and improving the management of Research and Development (R&D) projects. The method leans on the formulation and gradual and recurrent evaluation of quality criteria as a performance indicator of the work carried out. The way to develop the idea stands on the concept that quality is a measurable quantity that accumulates throughout the project.

The proposed project management methodology is built on three main aspects: Collaboration between University and Industry The correct interpretation of the TRL where research projects are developed The study of different metrics for project management, such as the measurement of the success of projects, the Key Performance Indicators (KPIs) of a project-based organisation, and the EQM

EQM is analysed, used and taken a step further by applying it to R&D projects and proposing new contributions for the definition of quality criteria, a holistic view of the method, the reinforcement of EQM, and a series of recommendations for its correct implementation.

The methodology has been tested with three actual use cases with different characteristics in terms of project size, funding and team members; and validated on an R&D Centre in Advanced Manufacturing in Aeronautics.

The pillars of the thesis are focused on the analysis of the mentioned components and their integration for the development of a methodology to improve the efficiency in the use of resources and quality of obtained results in the R&D projects' framework.

The results have been presented in four publications at academic conferences and three original papers submitted to scientific journals of the JCR' quartile one and two [5], and a final one in the final process of preparation. The key findings of these studies demonstrate

[5] Scopus Sources - https://www.scopus.com/sources.uri - Last Access: 20/12/2022

the effectiveness of using quality criteria for measuring progress in the management of R&D projects, as well as providing a better understanding of several critical aspects of the realisation of these projects.

Resumen

Los proyectos de Investigación y Desarrollo (I+D) se asocian constantemente con una serie de problemas endémicos como la probabilidad de fracaso, el alto índice de proyectos que terminan sin resultados, el alcance cambiante, el prolongado ciclo de vida y el choque entre los intereses de académicos y empresas cuando se realizan en colaboración. Además, los proyectos de I+D también se caracterizan por la dificultad de ceñirse a periodos definidos y a la planificación. El alcance de estos proyectos puede cambiar debido a factores internos y externos. Además, el nivel de preparación tecnológica ("Technology Readiness Level" o "TRL") en el que se desarrolla el proyecto de I+D determina sus características y retos. Por otra parte, la calidad del resultado de un proyecto de I+D sólo se aprecia al final de este. Este resultado está formado por la realización progresiva y acumulativa de las actividades que lo componen. Dependiendo además de varios rasgos, características y atributos que contribuyen a satisfacer las necesidades y expectativas de las partes interesadas.

El término Calidad, según la definición de la norma ISO 9000:2015 [2], es el grado en que un conjunto de características inherentes a un objeto cumple con los requisitos definidos. Dado que la calidad de los proyectos se construye de forma progresiva e incremental, se propone una metodología de gestión de proyectos de I+D en la que los criterios de calidad se definen y construyen conjuntamente entre la organización que desarrolla el proyecto y sus partes interesadas internos (Internal Stakeholders); para evaluar las tareas que se crean y así conseguir mejores resultados en los entregables del proyecto, así como para permitir la evaluación gradual de los resultados, el replanteamiento de los objetivos o el alcance y la pronta toma de decisiones sobre el proyecto. Todo ello para mejorar la eficiencia en el uso de los recursos y la calidad de los resultados obtenidos en el marco de los proyectos de I+D.

El principal objetivo de esta tesis es superar algunos de los problemas inherentes a este tipo de proyectos, desarrollando una metodología de gestión de proyectos basada en el Método de Calidad Ganada ("Earned Quality Method" o "EQM") y en el análisis de datos para mejorar la eficiencia de los proyectos de I+D en un entorno de producción casi real en un TRL 5-7.

La tesis se presenta por compendio de una serie de publicaciones que proponen medir y mejorar la gestión de proyectos de Investigación y Desarrollo (I+D). La metodología propuesta se apoya en la formulación y evaluación gradual y recurrente de criterios de calidad como indicador de rendimiento del trabajo realizado. La forma de desarrollar la idea parte del concepto de que la calidad es una cantidad medible que se acumula a lo largo del proyecto y se basa en tres aspectos fundamentales:

1. **El estudio de las características de la colaboración entre la universidad e industria.**
   El análisis de las diferentes características de la Colaboración Universidad-Industria ("University-Industry Collaboration" o "UIC") y cómo el tipo de proyectos generados

por éstas tienen características particulares, por ejemplo, estructuras de gobierno, propensos a conflictos de intereses, explotación de resultados, entre otros.

2. **La correcta interpretación del TRL donde se desarrollan los proyectos de investigación.**
Comprender el TRL del proyecto, la necesidad de progresar a un TRL superior y cómo generar una transferencia de tecnología y conocimientos de calidad entre las entidades implicadas en esta colaboración.
3. **El estudio de diferentes métricas para la gestión de proyectos, como la medición del éxito de los proyectos, los Indicadores Clave de Rendimiento ("Key Performance Indicators" o "KPI") de una organización basada en proyectos y el EQM.**
Analizar diferentes métricas aplicables a las organizaciones basadas en proyectos de I+D y cómo éstas influyen en los proyectos a realizar. Además, un enfoque basado en datos para el análisis de los diferentes criterios de éxito y la orientación hacia su cumplimiento y, por último, el uso de la calidad como concepto medible para evaluar el progreso del proyecto.

Durante el desarrollo de la tesis se analiza, utiliza y se da un paso más allá en el estudio del EQM aplicándolo a proyectos de I+D y proponiendo nuevas aportaciones para la definición de criterios de calidad, una visión holística del método, el refuerzo del EQM, y una serie de recomendaciones para su correcta implantación.

La metodología ha sido probada con tres casos de uso reales con diferentes características en cuanto a tamaño del proyecto, financiación y miembros del equipo; y validada en el Centro de Fabricación Avanzada Aeronáutica - CFAA [6] un centro de investigación público-privado en el área de fabricación avanzada en aeronáutica.

Los conceptos originales de la metodología se basan en dos fundamentos:

1. El trabajo de Paquin et al. [3] sobre el EQM, que se basa en la noción de que la calidad es un concepto medible y que la calidad se construye gradualmente a lo largo del ciclo de vida del proyecto.
2. El desarrollo iterativo e incremental como proceso que combina el método de diseño iterativo con el modelo de construcción incremental de los principios de las metodologías ágiles [4], que son complementarios y se utilizan a menudo para mejorar la eficiencia y lograr mejores resultados en los entregables de los proyectos

Por lo cual, los conceptos más importantes para la tesis son los siguientes:

- La colaboración entre organizaciones públicas y privadas para el crecimiento de la I+D en entornos locales mediante una rápida transferencia de tecnología.
- La identificación y medición de los criterios de éxito de los proyectos de I+D, tanto para los gestores de proyectos como para las partes interesadas.

[6] https://www.ehu.eus/en/web/cfaa/ - Ultimo Acceso: 20/12/2022

- La identificación de los indicadores clave de rendimiento para las organizaciones basadas en proyectos, sobre la base de los principios Lean mediante un enfoque basado en los datos.
- La identificación de criterios de calidad para un proyecto de I+D basados en factores de éxito, KPI organizativos y criterios definidos por el cliente; basados en un enfoque basado en datos para controlar la calidad del trabajo realizado y la calidad del producto entregado.
- La necesidad de desglosar los criterios de calidad en pequeños elementos para controlar el resultado de un proyecto.
- El desarrollo de una metodología de gestión de proyectos basada en el concepto de que la calidad es medible y alcanzable a lo largo del ciclo de vida del proyecto y en la generación de conocimientos para mejorar el rendimiento del proyecto.

Estas son algunas de las razones por las que la necesidad de controlar los proyectos de I+D se incrementa en tiempos tan turbulentos como los que vivimos. Buscar fórmulas para mejorar la eficiencia de las inversiones en I+D concedidas a entidades público-privadas, conseguir resultados de calidad de los proyectos y ser capaces de tomar decisiones a tiempo para evitar mayores pérdidas en I+D son algunas de las estrategias a seguir para limitar el impacto del actual contexto económico. Animados por el escenario socio-económico actual, nos planteamos como objetivo general crear una forma de llevar a cabo estas estrategias y así mejorar la eficiencia de los proyectos de I+D+i en un entorno de producción cuasi-real en un TRL 5 - 7, que se describirá en la Sección 4.1.8.

Este objetivo general se complementa a través de diferentes tipos de comunicaciones científicas con los siguientes objetivos específicos:

- Definir las estrategias de colaboración entre entidades público-privadas a través del estudio de centros de innovación relacionados cuyo objetivo es promover el crecimiento científico, económico y social de sus regiones mediante la colaboración con los sectores público y privado;
- Analizar el papel del TRL en la transferencia de tecnología y cómo afecta a las regiones que cuentan con este tipo de centros;
- Analizar las diferentes métricas de los proyectos de I+D, como el éxito de los proyectos y lo que significa para las partes interesadas, la identificación de los KPI para las organizaciones encargadas de desarrollar dichos proyectos y la medición del progreso de los proyectos a través de métricas de calidad;
- Desarrollar una metodología de gestión de proyectos de I+D basada en el análisis de datos para mejorar la gestión de este tipo de proyectos.

Los trabajos científicos presentados en esta tesis resumen la experiencia y conocimientos adquiridos a nivel teórico y práctico en la gestión de proyectos de I+D+i en centros público-privados en colaboración con la industria y ubicados en TRL 5 - 7, desde el inicio del análisis TRL en septiembre de 2019 hasta la definición de la metodología durante el 2022.

Pretendiendo describir el cumplimiento de los objetivos propuestos en esta tesis, comenzamos con un análisis del estado actual de centros de investigación como el CFAA, desde el punto de vista de la gestión de proyectos. Gracias a un estudio de benchmarking, un análisis general del estado actual de los centros y unas recomendaciones generales para el escenario del País Vasco. La investigación se desarrolló para comprender y profundizar en la cadena de producción y el TRL de los CFAA. En este apartado se ha publicado un trabajo de investigación [5].

Posteriormente, para la metodología, fue necesario analizar y estudiar el papel de la UIC para complementar el punto anterior. Por ello, se desarrollaron dos proyectos de investigación: i) el primero para conocer los patrones de cooperación internacional entre clusters de innovación [6], ii) el segundo consistió en analizar cómo crear puentes de cooperación entre estos clusters [7]. De esta forma, se pudo orientar hacia la consecución de objetivos a través de la metodología de gestión de proyectos y la mejor forma de medir estas colaboraciones en un entorno de proyectos de I+D.

Por último, se estudió la definición de los objetivos que deben supervisarse para el éxito de un proyecto de I+D mediante métricas de gestión de proyectos y un análisis basado en datos con tres enfoques diferentes: éxito del proyecto, EQM y KPIs.

El análisis del Éxito del Proyecto se realizó desde dos puntos de vista, el primero asegurando el éxito de un proyecto de I+D a través del estudio del ciclo de vida de la gestión de proyectos [8]. Aquí, se propuso una metodología híbrida de gestión de proyectos a través del análisis de las dimensiones de éxito de una organización de I+D, el análisis y la interpretación de la información y la literatura científica disponible en el momento. Los resultados fueron publicados en un documento presentado en una conferencia científica [9]. El segundo componente del éxito del proyecto se logró mediante la realización de un estudio utilizando la Metodología Q y entrevistas semi-estructuradas para definir los criterios de éxito de los proyectos llevados a cabo en una organización de I+D desde el punto de vista de la organización y sus partes interesadas [10]. Para el estudio de los KPIs, se investigó sobre la identificación de estos indicadores para organizaciones basadas en proyectos a través de un enfoque Lean, y los resultados de su desarrollo e implementación se publicaron en un artículo incluido en una revista científica [11]. Por último, para el estudio de EQM, su análisis y el estudio de su uso en proyectos de I+D+i se incluyó en un artículo de revista que resume la metodología de investigación creada. [7]

La metodología se puso en práctica y se probó en tres proyectos diferentes (una descripción ampliada de los proyectos puede encontrarse en la sección 4.1.8.4). El primer proyecto con financiación interna (UPV/EHU) en el que se desarrolló una plataforma de monitorización de máquinas en tiempo real. Los resultados se han presentado en un trabajo de investigación en un congreso académico [12]. Un segundo proyecto con financiación autonómica (Elkartek[8]), cuyo objetivo es predecir el desgaste de las herramientas de corte en operaciones de brochado. Los resultados se están recopilando, y el desarrollo

[7] Documento en proceso de publicación
[8] https://www.spri.eus/en/ekogarapena/ - Ultimo Acceso: 20/12/2022

y las conclusiones se presentarán en un trabajo de investigación que se encuentra en preparación.

Además, en el tercer proyecto se está desarrollando una tarea de un proyecto financiado con fondos europeos (Proyecto InterQ - Horizonte 2020[9]). La tarea consistía en crear sensores virtuales para el proceso de fabricación de una máquina mediante el análisis de los datos de calidad y proceso disponibles. Además, se publicó un artículo en una revista con el desarrollo y las conclusiones del montaje de la máquina para la recogida de datos, y el análisis [13]. Además, estamos desarrollando un segundo artículo de revista retomando las descripciones de los sensores virtuales, análisis de datos, y conclusiones de la investigación.

Los resultados de la tesis se han presentado en cuatro publicaciones en congresos académicos y tres artículos originales enviados a revistas científicas del cuartil uno y dos del JCR [10], y uno más en proceso final de preparación. Las principales conclusiones de estos estudios demuestran la eficacia del uso de criterios de calidad para medir los avances en la gestión de proyectos de I+D, además de proporcionar una mejor comprensión de varios aspectos críticos de la realización de estos proyectos.

[9] https://interq-project.eu/ - Ultimo Acceso: 20/12/2022
[10] Scopus Sources - https://www.scopus.com/sources.uri - Ultimo Acceso: 20/12/2022

List of abbreviations.

- **ACWP:** Actual Contribution of the Work Performed.
- **AM:** Additive Manufacturing.
- **CCS:** Critical Chain Scheduling.
- **CFAA:** Centro de Fabricación Avanzada Aeronáutica (Advanced Manufacturing Centre for Aeronautics: In English).
- **CNC:** Computer Numerical Control.
- **CP:** Control Points.
- **CPM:** Critical Path Method.
- **CSC:** Critical Success Criteria.
- **CSF:** Critical Success Factor.
- **CTQs:** Critical To Quality.
- **DEA:** Data Envelopment Analysis.
- **DMAIC:** Define, Measure, Analyse, Improve, Control.
- **EC:** European Commission.
- **EQM:** Earned Quality Method.
- **EQWP:** Earned Quality of the Work Performed.
- **EU:** European Union.
- **EVM:** Earned Value Management.
- **EVMS:** Earned Value Management System.
- **FoF:** Factories-of-the-Future.
- **FRED:** First Requirements Elucidator Demonstration.
- **IoT:** Internet of Things.
- **KPIs:** Key Performance Indicators.
- **KTTOs:** Knowledge and Technology Transfer Organisations.
- **MPCS:** Multidimensional Project Control System.
- **MRL:** Manufacturing Readiness Level.
- **NASA:** National Administration of Space Agency.
- **OEM:** Original Equipment Manufacturer.
- **PBEV:** Performance-Based Earned Value.
- **PCTI:** Science, Technology and Innovation Plan (in Spanish).
- **PCWP:** Planned Contribution of the Work Performed.
- **PCWS:** Planned Contribution of the Work Scheduled.
- **PERT:** Program Evaluation and Review Technique.
- **PLC:** Programmable Logic Controller.

- **PMO:** Project Management Office.
- **PMs:** Project Managers.
- **PPP:** Phased Project Planning.
- **PQWP:** Planned Quality of the Work Performed.
- **PQWS:** Planned Quality of the Work Scheduled.
- **QBS:** Quality Breakdown Structure.
- **QC:** Quality Criteria.
- **QPI:** Quality Performance Index.
- **QV:** Quality Variance.
- **R&D:** Research and Development.
- **SLR:** Systematic Literature Review.
- **SMEs:** Small and Medium Enterprises.
- **TRL:** Technology Readiness Level.
- **TTOs:** Technology Transfer Offices.
- **UIC:** University-Industry Collaboration.
- **VoB:** Voice of the Business.
- **VoC:** Voice of the Customer.
- **WBS:** Work Breakdown Structure.

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1

Introduction.

1.1 Presentation.

The thesis is presented by published papers from September 2019 to December 2022 about developing a data-driven project management methodology for R&D projects. The methodology is based on three main components:

1. **University - Industry Collaboration.**
   The analysis of different characteristics of University-Industry Collaboration (UIC) and how the type of projects generated by these have particular features, e.g., governance structures, prone to conflicts of interest and exploitation of results, and others.
2. **Technology Readiness Level.**
   Understand the project's Technology Readiness Level (TRL), the need for progressing to a higher TRL, and how to generate a quality transfer of technology and knowledge among the entities involved in this collaboration.
3. **Project Management Metrics.**
   To analyse different metrics applicable to organisations based on R&D projects and how these influence projects to be carried out. In addition, a data-driven approach to the analysis of varying success criteria and the orientation towards their fulfilment, and finally, the use of quality as a measurable concept for evaluating the project's progress.

The research was developed at CFAA [1], a public-private research centre in the area of advanced manufacturing in aeronautics. The original concepts of the methodology are based on two foundations:

1. The work by Paquin et al. [3] on the Earned Quality Method (EQM), which is founded on the notion that quality is a measurable concept and that quality is built gradually throughout the project's life cycle.

[1] https://www.ehu.eus/en/web/cfaa/ - Last Access: 20/12/2022

2. Iterative and incremental development as a process that combines the iterative design method with the incremental construction model of agile methodologies principles [4], which are complementary and often used to improve efficiency and achieve better results in project deliverables.

The term Quality (which can be used with adjectives such as poor, good or excellent), according to the ISO 9000:2015 definition [2], is the degree to which a set of inherent characteristics of an object meets requirements. Given that project quality is built progressively and incrementally, an R&D project management methodology is proposed in which quality criteria are defined and constructed jointly between the organisation developing the project and its internal stakeholders; to evaluate the tasks that are created and thus achieve better results in the project deliverables, as well as to enable the gradual evaluation of results, the rethinking of objectives or scope and the prompt decision making on the project. All of this is to improve the efficiency in the use of resources and the quality of the results obtained within the framework of the R&D projects.

The results of this thesis have been presented in four publications at academic conferences and four original papers in scientific journals of JCR quartiles 1 and 2. The findings of these studies demonstrate the effectiveness of using quality criteria for measuring progress in the management of R&D projects, as well as providing a better understanding of various aspects critical to the realisation of these projects.

The document's structure is ruled by the indications published in the **Chapter XI. Thesis by published papers - Regulations Governing the Management of Doctoral Studies**[2]

1.2 Motivation.

Industrial R&D investment in the European Union continued to increase in 2021 in European countries, making it the 12^{th} year of this trend. Six hundred seventy-eight companies invested 723.9 billion euros in R&D last year [17]. These companies showed promising results for most of their performance indicators, demonstrating that they are increasingly succeeding in capitalising on their R&D investment. However, many projects and novel ideas fall by the wayside. Lack of project control, poorly defined and ambitious objectives and R&D entropy are some factors that help keep the success rate of these types of projects from increasing [18].

R&D projects have a non-linear process [19] and are associated with extraordinary challenges, such as:

- the possibility of failure,
- the high rate of project completion without results,
- the variable project scope,

[2] https://www.ehu.eus/en/web/doktoregoa/doctoral-thesis/thesis-by-published-papers - Last Access: 20/12/2022

- the extended project life cycle,
- the conflict between researchers' and companies' interests,
- the difficulty of constraining innovation projects to defined periods and planning, and
- the non-fixed scope of innovation projects changes due to internal and external factors.

According to Mikulskiene [20], managing R&D projects involves unique planning, resource allocation, and scheduling issues because these projects require flexible planning to accept new methodologies and modifications.

Furthermore, R&D activities tend to be pro-cyclical, meaning that R&D moves in line with economic growth, and R&D investment decreases during recessions and increases during periods of economic growth. During recessions, different factors can influence R&D investments, e.g., falls in demand can lead to postponing innovative activities and investing this money in solving other areas of the company. The search for short-term gains is another factor affecting investment, as both R&D spillovers and the quasi-public nature of knowledge and its promise of long-term benefits are replaced by projects that seek to generate short-term profits.

Moreover, the quality of the result of an R&D project is seen only at the end of it. This result is formed by the progressive and cumulative realisation of the activities that make it up. It also depends on several features, characteristics and attributes that contribute to meeting the needs and expectations of the stakeholders. For example, although significant progress has been made in measuring project performance, there are still problems in correctly determining the performance of an R&D project for the above reasons.

An extended and widely validated method for measuring project performance is Earned Value Management (EVM). According to Vanhoucke et al. [21], an EVM system consists of a set of metrics to measure and assess the work of the current progress of projects relative to the expected progress as stipulated in the baseline schedule.

Another critical factor to consider is that project management in both the public and private sectors has distinct characteristics, not only because of a distinct and, on occasion, opposing focus but also because of practices, tools, resources, stakeholders, expertise, and experience, to name a few [22]. In companies, the incentives to complete a project are dependent on the measurable commercial results of the business. At the same time, for universities, it maximises measurable results derived from research (articles, theses, patents, and others.). For companies, universities are an almost inexhaustible source of knowledge too valuable and important to ignore [23].

However, according to Agrawal [24], when cooperation between the two sectors is sought, many endemic issues tend to arise in the management of shared R&D projects carried out in intermediate Knowledge and Technology Transfer Organisations (KTTOs) near the Technology Readiness Level (TRL) 5 to 7. As Yusuf mentioned [25], because companies need more assimilation methods, developing a product or service based on new technology can be challenging and hazardous. This approach necessitates the development of disruptive practices.

One of the core benefits of this collaboration can be seen by more researchers and company staff working with KTTOs, sharing experiences, points of view, and solutions to problems encountered during the execution of R&D projects. Several ways to measure the success of this collaboration can be set [26]. However, the most important is not just how many projects are being carried out but the success rate of those projects aligned to the organisation's Key Performance Indicators (KPIs). Alternatively, if it has adequately solved the problem, fit with the gap observed, or fulfilled the expectations and needs of the different stakeholders.

Limited access to public or private funding, a long payback period for some types of products or wrong market research can lead to the loss of efforts from many years in developing and researching new products. This phenomenon is intricate for large companies and Small and Medium Enterprises (SMEs). As a result, many ideas and discoveries developed at early TRLs remain in universities, with researchers unable to commercially capitalise on their innovations due to a lack of entrepreneurial skills, business know-how and contacts needed to gain access to the business world [25].

However, these intermediate KTTOs are fundamental and essential instruments within the innovation process to be dismissed. Fortunately, a new way of managing companies, projects, and universities based on data is emerging thanks to Industry 4.0.

In this new era, large amounts of data are available within companies, universities, and KTTOs; and different types of data analysis techniques rise to maximise the benefit from this data, allowing to develop of new processes, tools, practices, and theories in project management to improve the control of projects, even in harsh environments such as KTTOs or an R&D environment.

Given these conditions, quality assurance is essential during the project life cycle (from the customer's and project team's approach). This is why, based on the premise that quality is a quantifiable quantity and following the client's and project team's expectations, this thesis is proposed to analyse measures to control and assess the project's quality performance throughout its life cycle. It also highlights how the use of information to establish significant quality deviations is intended to help Project Managers (PMs) make timely choices to rectify the project's path.

The most important concepts for the thesis are the following ones:

1. Collaboration between public and private organisations for the growth of R&D in local environments through a quick technology transfer;

2. the identification and measurement of success criteria for R&D projects for both PMs and stakeholders;

3. identification of KPIs for project-based organisations based on lean principles through a data-driven approach;

4. the identification of quality criteria for an R&D project based on success factors, organisational KPIs and client-defined criteria; based on a data-driven approach to control the quality of the work performed and the quality of the delivered product;

5. the need to break down quality criteria into small pieces to control the outcome of a project;

6. the development of a project management methodology based on the concept that quality is measurable and achievable throughout the project life cycle and on generating knowledge to improve project performance.

These are some reasons why the need for control R&D projects is increased in times as turbulent as the ones we live in. Looking for ways to improve the efficiency of R&D investments given to public-private entities, achieving quality results of the projects and being able to take decisions in time to avoid further R&D losses are some of the strategies to be followed to limit the impact of the current economic context. Encouraged by the current socio-economic scenario, we set a general objective to create a way to carry out these strategies and thus improve the efficiency of R&D projects in a quasi-real production environment in a TRL 5 - 7, which will be described in Section 4.1.8.

This general objective is complemented through different types of scientific communications with the following specific objectives:

1. To define the collaboration strategies between public-private entities through the study of related innovation centres whose objective is to promote scientific, economic, and social growth in their regions through collaboration with the public and private sectors;
2. to analyse the role of the TRL in technology transfer and how it affects regions with such centres;
3. to analyse different metrics of R&D projects, such as the success of projects and what it means for stakeholders, the identification of KPIs for organisations in charge of developing such projects and the measurement of project progress through quality metrics;
4. to develop an R&D project management methodology based on data analysis to improve the management of this type of project.

The scientific papers presented in this thesis summarise the experience and knowledge acquired on a theoretical and practical level in the management of R&D projects in public-private centres in collaboration with industry and located in TRL 5 - 7, from the beginning of the TRL analysis in September 2019 to the definition of the methodology in December 2022.

Intending to describe the fulfilment of the proposed objectives of this thesis, we begin with an analysis of the current state of research centres like the Advanced Manufacturing Centre for Aeronautics - CFAA (in Spanish) [3]) from a project management point of view. Thanks to a bench-marking study, a general analysis of the current state of the centres and some general recommendations for the Basque Country scenario. The research was developed to understand and go deeper within the production chain and the TRL of the CFAA. A research paper has been published in this Section [5].

After that, for the methodology, it was necessary to analyse and study the role of university-industry collaboration to complement the previous point. Therefore, two research projects were developed: i) The former to understand the patterns of international cooperation between innovation clusters [6], ii) the latter was to analyse how to create bridges for cooperation between these clusters [7]. In this way, it was possible to orientate towards the pursuit of objectives through project management methodology and the best way to measure these collaborations in an R&D project environment.

Finally, the definition of the objectives to be monitored for the success of an R&D project through Project Management Metrics and a data-driven analysis with three different approaches, Project Success, EQM and Key Performance Indicators (KPIs), were studied.

The analysis of Project Success was carried out from two points of view, the first one ensuring the success of an R&D project through the study of the project management life cycle [8]. Here, a hybrid project management methodology was proposed through the analysis of the success dimensions of one R&D organisation, analysis and interpretation of information and scientific literature available at the time; the results were published in a paper presented at a scientific conference [9]. The second component of project success was achieved by conducting a study using Q-Methodology and semi-structured interviews to define the success criteria of the projects carried out in one R&D organisation from the point of view of the organisation and its stakeholders [10]. For the study of KPIs, research was carried out on identifying these indicators for project-based organisations through a lean approach, and the results of its development and implementation were published in a paper included in a scientific journal [11]. Finally, for the study of EQM, its analysis and the study of its use in R&D projects was included in a journal paper summarising the research methodology created. [4]

The methodology was implemented and tested in three different projects (An expanded description of the projects can be found in Section 4.1.8.4). The first project with internal funding (UPV/EHU) in which a real-time machine monitoring platform was developed. The results have been presented in a research paper at an academic conference [12]. A second project with regional funding (Elkartek[5]), in which the aim is to predict the wear of cutting tools in broaching operations. The results are being

[3] https://www.ehu.eus/en/web/cfaa/home - Last Access: 20/12/2022
[4] Paper in the process of publication
[5] https://www.spri.eus/en/ekogarapena/ - Last Access: 20/12/2022

collected, and the development and conclusions will be presented in a research paper under preparation.

Furthermore, the third project was developing a European-funded project task (InterQ Project - Horizon 2020[6]). The job was to create virtual sensors for the manufacturing process of a machine through the analysis of available quality and process data. In addition, one journal paper was published with the development and conclusions of the machine assembly for data collection, and analysis [13]. In addition, we are developing a second journal paper resuming the descriptions of the virtual sensors, data analysis, and conclusions of the research.

We present the papers published at academic conferences and in scientific journals in this thesis, accompanied by the papers presented.

1.2.1 Personal motivation.

The motivation for researching this topic stems from the awareness of the need to use better the resources allocated to research. The research's main objective was to find a way to improve the efficiency of the resources available during research. Contrary to what experience dictated, the researcher set out to find ways in which R&D projects are more researcher-friendly, valuable, high-quality, classifiable and defensible results are obtained, and the money invested bears fruit that can benefit society.

There are many ways to do this. First, data analysis alone can help the administrations and control bodies of companies and research centres to use resources allocated to research and development. However, the denaturalisation that comes with pragmatic data analysis dehumanises project management.

Above all, project management is based on managing people rather than developing a data pipeline to get a job done. Therefore, a mix of the two worlds, data-driven and project management, is an approach that can be beneficial to the discipline and can help to fulfil the motivation.

[6] https://interq-project.eu/ - Last Access: 20/12/2022

2

Theoretical framework and methodology.

2.1 Introduction.

Based on the concepts developed in the previous Section (See Section 1.1), this theoretical framework aims to set up the basis to formulate a new data-applied and knowledge-based project management methodology for R&D projects on KTTOs, which demands an understanding of:

- University-Industry collaboration (UIC) characteristics;
- TRL function between technology and knowledge transfer;
- Project management metrics for R&D projects:
  - Project Success;
  - KPIs;
  - quality measurements.
- Project management methodologies for R&D projects.

2.2 Theoretical Framework.

2.2.1 University-Industry collaboration.

Dramatic changes in the last decades have transformed the organisation of modern life, and universities, as a fundamental part of modern society, have not been immune to those changes. Universities serve a critical role in training the next generation of specialised, informed individuals while disseminating information. On the other hand, companies are swiftly adapting to changing situations, analysing and evaluating the risks and possibilities they face.

2.2.1.1 Contextual perspective.

During the 1980s, Europe feared losing its leadership role to emerging countries due to economic slumps. The European Commission thrives on regenerating the technology program to create competitive European industries with the active collaboration of universities to increase investment in applied research, development, and innovation activities. Governments at all levels urged universities to make more outstanding contributions to their national innovation systems. As a result, universities flourished as essential players in regional development activities, which eased innovation-based growth [27].

New roles have emerged for universities alongside the growing importance of knowledge production and innovation, creating both the opportunity for and the necessity to rethink the meaning of Universities as the active member of the society they were. Privileges, roles, resources, tasks, and duties needed to be analysed and reformed to occupy and fulfil the role they were given.

Even though that UIC is far from being a novelty [28], over the past decades, efforts to enhance this collaboration have been widely supported. Local companies, governments, and society pressure universities to be more involved and relevant. Universities responded accordingly by opening themselves up to external agencies and actors, engaging with society and increasing their contributions, facilitating the emergence of a 'Third mission' [29]. However, universities were not only asked for involvement and relevance but were also charged with tasks involving legitimacy, governance, marketisation, internationalisation and exploitation of higher education results [30].

Internationalisation for universities arrived in the Bologna Agreement, which located them into structural reforms of their programs and curricula to enhance consensus and alikeness among degrees across Europe, giving students far more options and more diversity in planning programs. Furthermore, the Bologna Agreement increased access to research collaborators and opened universities up to disputes with and comparisons against universities in other countries [14].

Commercialising academic knowledge is one of the best ways to generate the academic impact pursued by universities due to the easy measurement of the market acceptance for the outputs of academic research [31]. Similarly, universities are setting up Technology

Transfer Offices (TTOs) with internal support functions and procedures to foster the technology transfer process to industries.

The third mission is referred to Universities' social, entrepreneurial, and innovative activities, in addition to their teaching and research missions that result in additional societal advantages [32]. The previous years have seen an increasing emphasis on improving activities related to this mission, contributing to changing their stakeholder expectations of what universities can achieve.

Besides the traditional two pillars in academic teaching and scientific research, the Third mission is about how consciously and strategically universities contribute and deliver benefits for their societies in four significant areas of activity: continuous education, technology transfer, innovation, and social engagement [29]. However, despite all this, the idea of the third mission emerged from within the system. Moreover, it emerged as a university response to a broader set of drivers motivated by a different set of aspects, such as an increasing need for funding, scientific knowledge impact, knowledge production and competitiveness **Figure 2.1**.

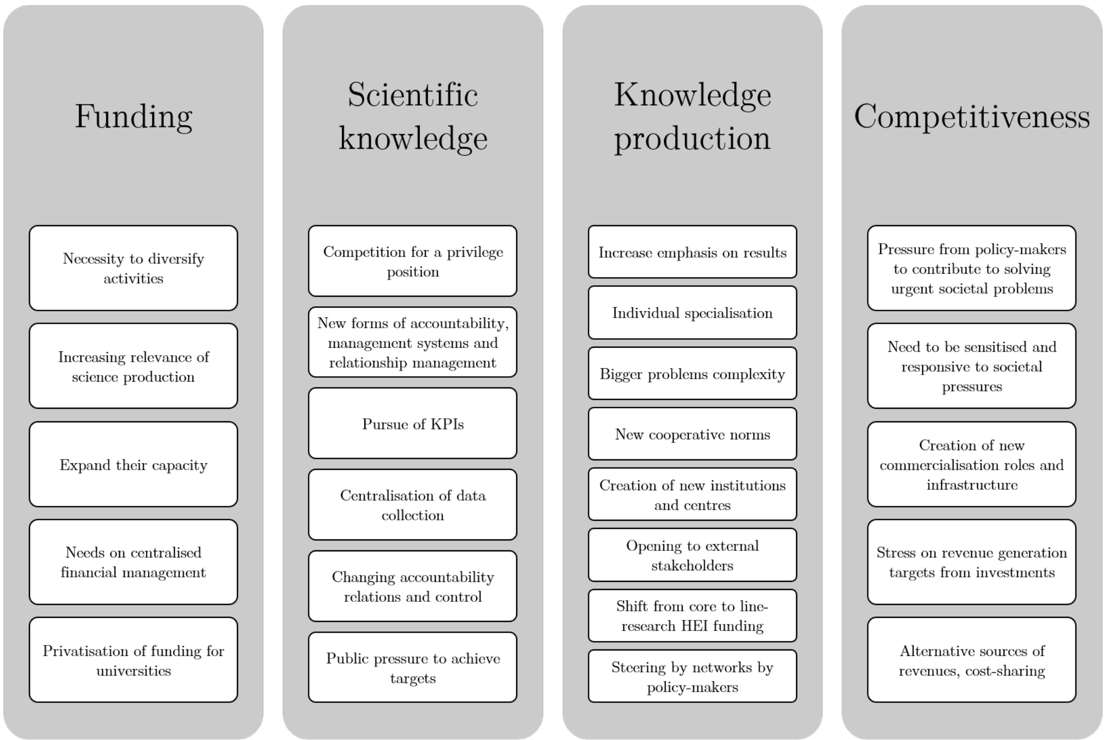

Fig. 2.1: Drivers for university third mission [14].

Hurmelinna [33] has listed a wide variety of potential motivations for UIC, which vary according to the company's size, culture or geographical location. At the university side, they can be summarised (but not restricted) to the enhancement of teaching, access to funding/financial resources, the source of knowledge and empirical data, political pressure, reputation improvement, and job offers for graduates [34]. For universities, not engaging in such collaborations takes them away from these benefits and creates an atmosphere of isolation which, due to an increasingly globalised environment, cannot be afforded.

2.2.1.2 About innovation management.

According to Porter [35], territories need to develop innovative strategies to build competitive advantages based on their existing resources, skills, capacities, and trends. The relationship between the university, government and industry (triple helix model [36]) is considered an essential element for the third mission. Furthermore, it is beneficial for classical universities because the realisation of transdisciplinary activities conducted outside the university helps them to create applied research and education, making them more realistic, applicable, and relevant for society and economy [37].

Traditionally, industries enunciate a problem situation to universities and wait for a solution because of the research carried out. However, this has not been satisfactory and lacks the involvement of critical stakeholders and a clear mission, order, and vision from both sides. Nowadays, the company usually sees the importance of this collaboration to obtain more successful and innovative research results [34].

As UIC develops, society and industries are increasingly motivated by the added value of their products and processes and the opportunities arising from the intense collaboration. This has caused a dramatic change for universities and transformed them into open institutions that became active players within the regional innovation system. The necessity of enhancing knowledge transfer between public research institutes and business was recognised by the European Commission (EC) as one of the ten crucial areas of action in the European Union's (EU) innovation policy [38].

In terms of product-supplier relations and access to tacit and explicit knowledge and labour supply, universities and local governments enhance local companies' innovation processes and become a sustainable source of practical knowledge and a driving force of technology exchange [6].

Although companies now recognise knowledge as a fundamental asset and the primary resource to boost innovation and increase productivity through knowledge exchange, the acquisition and absorption of external knowledge, resources, and technology are challenging because their producers and users come from different environments [39]. This knowledge allows companies to raise several diversification strategies supported by local governments pursuing their transformation based on competitiveness through efficiency to one based on innovation.

According to UNE 166001:2006, innovation is the *"application of new or significantly improved methods, techniques, or supplies in any activity whose objective is to obtain new products or processes or significant improvements in existing ones"* [40]. Despite this clear definition, in the academic literature, there is no joint agreement about why, where, and how it occurs [41].

Innovation *per se* is not an isolated process. It is composed of the interaction between stakeholders with different knowledge, experience, and understanding, and depends on a complex mixture of factors [42] like:

- Economic circumstances;
- company maturity level;
- government support;
- university capacity for R&D processes;
- access to qualified personnel, among others.

However, recent innovation processes have become more difficult due to pressure from the industry for faster technological evolution to compete with international markets and the shortening of the product life cycle. In comparison, the university must grow in technical knowledge and fulfil a broader social role. Likewise, research clusters focused on technology transfer are required to increase funding for new research activities and equipment to generate theoretical and practical knowledge.

2.2.1.3 University-Industry Collaboration' Characteristics.

Policymakers tend to focus on short-period investments where they can achieve results as soon as possible as a booster to their campaigns in their next elections. Naturally, more attention is being paid to organisations that act as KTTOs intermediaries in the innovation process that could accelerate the obtaining of results.

The efficiency of these collaborations is a crucial issue for policymakers [27] because the results achieved can be easily transferred to the industry quickly and effectively, contributing to the growth and good health of the economy. This reflects on universities by forcing them to develop collaboration strategies with regional industries and other universities and with the industries or university members of the international innovation ecosystem.

Publicly or privately (or a combination of the two) funded KTTOs housed in universities or public research organisations; publicly funded regional economic development agencies; knowledge-intensive business services organisations; professional associations; advisory bodies; or knowledge workers; could all be viewed as intermediaries that facilitate knowledge transfer in support of the innovation process in businesses [43]. These intermediaries are *"organisations or bodies that act as agents of brokers in any aspect of the innovation process between two or more parties"* and are crucial nodes connecting suppliers to the users of knowledge [44]. All types of innovation intermediaries share four functions [45, 46, 47]:

1. to connect actors between universities, industries, and governments;

2. to involve, engage and mobilise actors for companies of all sizes, universities, R&D Centres, and others;
3. to solve, avoid or potentially mitigate conflicts of interest between actors;
4. to actively stimulate the innovation process and innovation outputs.

KTTOs provide help to companies in the process of extracting value from knowledge so that they can enhance their inner potential for innovation. However, policymakers need to understand this transfer process better because of a lack of information regarding their contributions to the innovation process. Improving marketing strategies at universities and companies towards their collaboration and the quality of information disseminated regarding the contribution at the different stages of the innovation process of companies can help to overcome this issue [45].

As mentioned earlier, universities and companies pursue several objectives. First, users and knowledge producers belong to different communities separated by a 'valley of death' [48] and are governed by different incentives. On the one hand, companies focus on acquiring essential knowledge that may be used for competitive advantage. Companies are ready to generate a profit and apply the research findings to their operations as quickly as feasible. However, they do not feel compelled to publicise their results because they are concerned about losing their competitive edge.

On the other side, what moves universities is the responsibility to create new knowledge and to educate. Universities are actively looking to work with companies to acquire funding for their graduate students and lab supplies, augment their research, field-test the use of their research, and gain fresh insights[49]. They take a longer-term view of their job, seeking regional and international recognition through the more significant effect of their publications, research project results, scientific staff quality, leadership or involvement in international initiatives, and the quality of their research. Most academics engage with industry to further their research rather than commercialise their knowledge [50] and are generally in favour of close collaboration in technology transfer, especially if this is tied to regional economic development than companies' profits.

Furthermore, UIC involves people with different competencies, knowledge, expertise, experience, and points of view, which is remarkably important for innovation. However, these different points of view can drive breaches in communication resulting in misunderstandings and preconceptions during the project. However, since they share a common temporal goal, there is a need to create a culture of collaboration to find common ground and effective communication to understand each other's perspective and create a stable and fruitful long-term partnership.

Different advantages of UIC can be achieved, but they rely on the desire for improvement from both sides, the free flow of information, and the willingness to cooperate. Companies need to make out the best possible way to obtain benefits from the knowledge within their organisations, and universities need to deeply understand and connect to the conditions in the industrial environment. Both actors need to understand the importance of collaboration and to know that occasionally they cannot have what they want but can get what they need [51].

Although there is a greater willingness to transfer knowledge between universities and companies, many initiatives have been ineffective[52]. Managing the differences described is challenging and demands mechanisms to communicate and produce a shared understanding to align the different views and preconditions. Dealing with complex stakeholders, fast-changing processes, diverse teams' characteristics, and inter-and transdisciplinary work requires project management competencies, a tailored set of processes, tools and methods, and a projectized approach to manage UIC. The advantage of this approach relies on the fact that a set of specific goals in terms of quality or scope for each effort can be achieved, along with an assessment of the involved stakeholders' interests and processes and tools to perform each task of the project that can reach to a common plea or objectives of those stakeholders [53].

The interpretation of objectives is one of the main factors for the generation of errors in UICs, the problems to be solved together with the activities necessary to achieve the project objective increase the risk of misunderstandings between the partners and hinder the integration of their project team [54]. This is one of the reasons why great efforts should be devoted to providing tools and promoting effective communication between project members of the two organisations that provide immediate feedback.

When the realisation of project tasks depends on the collaboration members, the need to share data during the collaboration becomes crucial [55]. As this interdependence increases, mechanisms for coordinating the partners' tasks become necessary [56]. Therefore, a project management approach that considers the various characteristics we have outlined is essential for project success and collaboration.

2.2.1.4 Project management approach for University-Industry Collaboration.

One essential success factor in evaluating UIC is the organisation's ability to transfer its knowledge effectively [57]. Effective collaboration management can mean whether or not technology can be successfully transferred and research results commercialised.

As we have seen, companies are increasingly open to collaborating with universities to pursue further innovation and R&D projects. The industry has recognised the value of collaborating with universities to improve their internal innovation capabilities [58]. Not having such collaborations increases the likelihood of not meeting stakeholder expectations [59], which may also be weakened due to a lack of trust in partners, insufficient clarity of objectives, poorly assigned responsibilities and planning, and absence of flexibility and agility within the management structure. [60].

There are several critical success factors for successful UIC projects, among them:

- The need for a high level of trust at both individual and organisational levels [61].
- Collaborative know-how, drawn from past relationships [61].

- Clarity of the proposed objectives.
- Assigned responsibilities, together with planning, flexibility and agility within the management structure [60].

Most studies to understand UICs have focused on the outcomes of it rather than on the practices and mechanisms deployed during their implementation [62].

Wolff et al. [63] mentioned that it is essential for academia and project management practitioners to provide and prove the successfulness of new processes, tools, and methods for innovation and entrepreneurship management. Constant communication, co-creation of a sense of a 'project team', active and dynamic collaboration, data sharing, constant and short-cycle feedback, responsiveness to changing needs and the ability to adapt to new strategies based on new knowledge and data, minimising the risks arising in conventional approaches to managing research collaboration, can be reached through a projectized approach [64]

Research conducted by Ankrah & Al-Tabbaa [65] revealed that one of the most critical aspects to facilitate the operation of UIC is determined mainly by management and organisational aspects, such as leadership / top management commitment and support, collaboration champion, teamwork, communication, corporate stability, organisation culture and structure, firm size, absorptive capacity, skills and roles, personal exchange; but undoubtedly one of the most important is project management.

A proper project management approach can improve many of the difficulties encountered in the UIC, including lack of trust between the parties, lack of definition of shared objectives, conflicts of interest, and others. However, this is a challenging thing to do. As we have seen, R&D projects are inherently complex, where it needs to be known what the outcome will be and whether it can be achieved.

To correctly manage such collaborative projects, it is necessary to examine their characteristics. For example, Mikulskiene [20] discusses the project's complexity owing to its high level of uncertainty and risk since it involves unusual tasks such as breaking down barriers, changing collaboration, and identifying breakthroughs. On the other hand, their objectives are usually ambitious, optimistic and challenging, so it is common to encounter changes during the project by rethinking the objectives, changes in the implementation of the initial ideas (which generates changes in the planning of tasks), change of research methods [66], change in stakeholders or the applicable regulations. However, it is possible to complete the project's scope through iterative and progressive investigations.

We could summarise the main challenges of conducting these projects as follows:

- Non-linear development processes [19];
- high probability of failure;
- high rate of projects completed without results;
- variable project scope;
- long project life cycle;

- conflict of interest of researchers and companies;
- difficulty in defining the duration of the project;
- complex planning;
- poorly defined objectives;
- stakeholder management.

Similarly, detailed planning of tasks and project phases is a challenging task. The lack of clear, defined and often achievable objectives makes this task very difficult. As a rule, the planning, resource allocation and scheduling of tasks are often fraught with problems, so flexible planning to cope with these changes is more than necessary [20].

At the start of a project, a realistic description of the project objectives helps project teams focus their efforts on tasks and activities that will lead to the stated objectives being met. In addition, a detailed description of the research objectives favours the comparison between the results achieved and those planned during the project development. Furthermore, adequate control of these tasks and activities will allow PMs to analyse the causes for not achieving the objectives and to propose preventive measures for future projects. Finally, the standardisation of results is necessary to align partners' activities at UICs effectively.

These management practices depend on the degree of decentralisation sought in the project and are aligned with the organisations' objectives in terms of knowledge transfer. For example, research conducted by Morandi [55] reveals that these coordination and cooperation control activities are organised differently, depending on the degree of uncertainty in the tasks, the failures that occur during the project life cycle and the interdependence between project teams, which characterise R&D projects in UICs.

The planning of activities from the early stages of the project is more important than the internal R&D process, as they aim to create the standard framework for how the project in question will be approached. This helps overcome some innate differences that characterise industry and academia when undertaking joint collaborative projects. However, despite the effort put into planning the activities, these initial plans only sometimes provide a straightforward narrative of how the intended objectives will be achieved, not to mention a detailed description of the opportunities and challenges of the project, quickly leaving them obsolete. Unless there is a continuous review of the objectives and proper management of project risks, despite all this, the initial planning of activities is desirable, as it allows the partners' efforts to be aligned.

A correct approach to project management helps to implement better both the initial setting of objectives and the planning of the activities to be carried out during the project. In addition, it provides a series of control practices to verify the gradual fulfilment of the project's intermediate objectives. In UIC R&D projects, these control practices are closer to those applied in internal R&D projects than in strategic alliances, where written reports and periodic meetings to monitor objectives are effective means of control [55].

This is why the usual project management methodologies often need to fit better for this type of project due to the rigidity of the processes and the sometimes-exuberant amount of documentation required. On the other hand, it is not possible to go to the other extreme and leave everything to the natural entropy of the project, but to find ways that can give flexibility to the processes, that make it possible to evaluate progress throughout the project life cycle, that take into account the requirements and changes that stakeholders may present—that help to evaluate results from the earliest stages. The natural evolution for managing such projects should be towards more hybrid approaches that include both traditional and agile practices.

However, here a disclaimer must be made. How these projects are managed also depends entirely on the project size. While classical project management methodologies provide stability and practices needed to maintain a large project on track, such as the management of the university-industry collaboration agreement itself, agile or hybrid methodologies for small and medium-sized projects have proven to be more effective, as they provide closer control over objectives and reduce the documentation, formalities and requirements of classical methodologies, increasing both stakeholder satisfaction and the quality of the research results [67].

Another aspect of the suitability of using hybrid methodologies for this type of project is that more extensive control over, for example, intellectual property rights or knowledge transfer is often bound by the contractual agreements for this type of collaboration. Beyond this, the mutual trust between partners and the personal relationships between team members, built on previous collaborations, leads to overlooking the need for more extensive control over research.

Equally crucial to a projectized approach to help solve some of the issues presented by UIC is the need to find a common language on what is concerned with the situation of the projects. Fortunately, the TRL that was born initially as a tool to explain to suppliers of the National Administration of Space Agency (NASA) about the level of readiness of a technology required to participate in a mission is now being widely used by different industries, and that has resulted in a straightforward language to communicate with universities. Recently, universities have been using it to understand differences between companies, approaches, and progress inside one research project or technology.

2.2.2 Technology Readiness Level.

One of the key goals in the history of NASA's evolution was successfully putting a man on the moon. However, a significant gap emerged between ordinary people and the Agency once this objective was reached. As long as NASA delivered increasingly successful missions, people decreased their interest in what they were doing. Not just because of a lack of understanding but also because NASA itself needed to be more easily transferring its knowledge, goals, strategies, and methods to people [68], leaving aside the fact that without the support of the North American people, NASA could not survive.

Several strategies were put on track to close this gap. First, regular people were invited to participate in space missions, and even a child was chosen to be trained as the next astronaut, looking to show that anyone could become one. Along with it, reforms inside the Agency were developed to enhance the collaboration between universities and technology companies interested in participating in the Space Program. The space policies born in the 1980s aimed to unify the criteria in terms of capabilities and skills necessary to collaborate with NASA. One of these objectives was to develop *"a solid base of national capabilities and talent to serve commercial and other space sector interests"* [16].

The development of R&D projects in which the design of complex or highly technology-based systems is sought are typically characterized by a series of demanding requirements. They are also designed with a high level of uncertainty regarding their architectures and components by often interdisciplinary teams that mix researchers from university and company staff. The uncertainties generated are natural and result from the project's novelty and the proposed system's high technological content.

When this type of project is presented, different contexts surrounding the university and industry create the need to develop mechanisms to communicate and understand the interests of each of them. Facilitating the understanding between the parts as well as aligning the different points of view and preconditions is vital for the success of these projects. A more straightforward way of characterising the depth to which technological research or development should proceed was also required [69]. In this way, TRL clarifies for everyone the readiness level of technology to participate in a NASA mission, comes to act as a common language between the parts and clarifies several aspects related to the situation of the project, the research stage, or what is needed to achieve the objectives that were set.

They are conceived initially as a seven-level metric (**Table 2.1**), the TRL provides the basis for mutual understanding on technology agreements between research staff, management, and mission flight program managers [16]. It is also a systematic method of measuring the maturity of a particular technology and the consistent comparison of its evolution among different types of technology. It also allows visualizing in a graphic way the innovation strategies, works as well as a reviewer of the quality assurance and gives a particular perspective on time needed to fulfil the project. TRL has a variety of proven uses in aerospace systems engineering and project management, including tracking a technology's maturity and helping to balance cost, schedule, and risk management. Furthermore, it effectively divides and displays the basic categories of research, feasibility, development, and demonstration.

TRL	**Description**
Level 1	Basic principles observed and reported.
Level 2	Potential application validated.
Level 3	Proof-of-concept demonstrated analytically and experimentally.
Level 4	Component and breadboard laboratory validated.

Level 5	component and breadboard validated in the simulated or real-space environment.
Level 6	System adequacy validated in a simulated environment.
Level 7	System adequacy validated in space.

Table 2.1: Original TRL model [16]

As has been described, TRL takes a particular technology from the approach of fundamental principles, validation of the concept, demonstration through a prototype, and successful operation. The main goal of the tool is to include external skills that can provide new information and experience essential for the growth and improvement of the innovative capacities of businesses and institutions.

However, TRL is used to understand the maturity of the technology and to communicate the maturity of a methodology, concept, and development of internal and external projects. Companies have been using TRL since the mid-1990s and have been adapting the tool to obtain government funding for R&D projects. Some authors have described that TRL classification can serve not only as a measure of the maturity of a technology but also as a measure of its readiness to be integrated into a more extensive system. TRL is currently being used to monitor the maturation process within a technology development process and to state expectations on categorizing research projects. Moreover, knowing the status of the research serves as input for establishing long-term partnerships and research initiatives within the company.

There is a great deal of empirical research indicating the importance of external sources of knowledge, resources, and technology in the development of innovation in companies [70], and not just in NASA. Even though much of a country's capability for innovation resides at universities, the tool is not commonly used in academia and is only used in some collaborative research projects. Moreover, the tool is expanding, and those who have used it describe it as a helpful instrument for communicating with the academy regarding the development of processes and their different stages. As a result, its use has become more popular, and those companies who have used it describe it as helpful in understanding the university regarding the development processes and the different stages of the research project [42].

Depending on the sector or the objective in which the TRL is applied, it is optional to reach all levels. The technology, system or process may be valuable if it only reaches the basic levels of the TRL. However, the results are only valuable if they reach the final stages of the tool. Each stage of the TRL has associated risk criteria depending on the level at which it is being worked. The risks of putting a successful prototype in actual conditions differ from those of previously submitting the same prototype for evaluation into simulation software. Understanding, describing, and controlling the evolution of these risks, depending on the case of the technology or the project to be completed, is a critical task for correct management through the project life cycle and to ensure that it achieves the desired benefits. However, when considering these risks, not only those associated with the development of the technology (inner picture) must be considered, but also the risks associated with the adoption of the technology (broader picture), which in many cases may determine the use or not of the final result of the project.

In the 1990s, the TRL evolved to a nine-level classification to broaden the vision and be clearer at each level. At that time, the TRL was clearer as a tool to monitor and evaluate the technology development process, to provide a criterion for categorizing research projects and a scale to compare technologies. Furthermore, it provides stakeholders with a single language to comprehend the underlying technology, the technological demonstration to be achieved, the product prototype or product project development, and, most importantly, to assess the efficacy of technology transfer.

Although it was initially intended only for NASA suppliers [68], long-term relationships could be built for developing a specific technology or research project. However, despite its spatial focus, its uses soon became common because its final results could be easily adapted to assess the readiness of a particular technology, product or system required for and specific objective in almost any sector.

Each level within the classification is essential, as they lay the foundation for progress at subsequent levels and provide information to make future decisions. The tool is based on engineering assessments to communicate signs of progress and hypotheses and categorize them within the process management and external stakeholders' point of view.

2.2.2.1 Definition of Technology Readiness Levels.

A general outline of each level will be described to understand the relationship between the stages. **Figure 2.2** provides an overview of the TRL and the phases of development.

TRL 1: Basic principle observed and reported.
The bottom layer of TRL is where the basis of the evolution or the use of a particular technology is set. Basic scientific research starts at this level by observing and reporting some or any exciting characteristics about a particular subject (material, programming language, the usability of technology, and others.). For example, Additive Manufacturing (AM) technology has acquired relevance and interest in academia and industry during previous years because it allows the creation of complex geometries with customizable material properties.

A practical example of the TRL 1 related to AM would be a KTTO, university, or company noticing the design versatility of the technology, the potential lightness of the structure, or the material properties produced by the technology.

TRL 2: Technology concepts and application formulated.
Once the basic principles have been observed, the process can be formulated to identify some potential uses of the topic in question (material, programming language, the usability of technology, and others.). At this level, the uses or applications are still entirely speculative, and supporting the formulations with more specific experiments or detailed analyses is still optional.

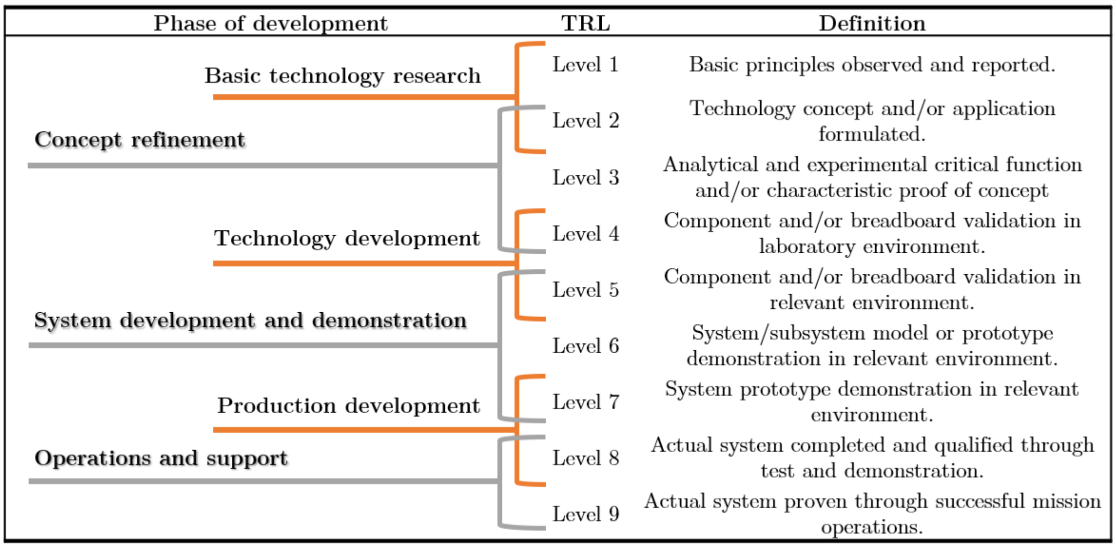

Fig. 2.2: TRL and phases of development, based on [15].

Continuing with our example of AM technology, the next step that fits at this level is replacing an active component of a complex system, such as an engine component, with a part designed and manufactured using AM.

TRL 3: Analytical and experimental critical functions and characteristic proof-of-concept.
At this level, once the conceived concept has been formulated, an active research and development process is initiated to bring the idea to maturity. It is then necessary to include analytical studies to place the technology in an appropriate context and to carry out laboratory verification to validate that the analytical predictions are physically correct. In a few words, what is sought on this level is the proof-of-concept' validation through analytical and experimental approaches to applications or concepts formulated at the previous level.

For our example of AM technology, the next step that fits this level is the design of the piece or component, validated through CAD/CAM/CAE software simulation.

TRL 4: Component and breadboard validation in a laboratory environment.
Once the 'proof-of-concept' is analytically and experimentally validated, the process of confirming its functionality inside the system starts. This process must serve as the best support of the concept formulated and should accomplish the requirements of the potential system applications. To carry out this activity, specialized organizations or companies should participate side-by-side in the evolution of the concept. Not just because of the knowledge and experience gained by participating throughout the evolution of the concept but also because, at this level, the cost of the research starts to rise (depending on the technology), so some formal sponsorship should be sought and attained, for example, through governments or industry investments.

In our example of AM technology, the study of the piece or concept's manufacturing parameters should be analyzed and completed. At the same time, validation within the final ensemble should be carried out to ensure that the characteristics of the concept meet the requirements of the final system in which it will be installed.

TRL 5: Component and breadboard validation in a relevant environment. The accuracy of the tested concept is significantly improved by experimentation at TRL 4, enabling integration into the system with suitable supporting components and enabling testing of the full implementation of the entire system in a simulated or realistic setting. This process may include one to several new technologies in the demonstration. This activity should be carried out in specialized facilities only available to formal R&D organizations or corporate laboratories. However, it should also involve formal sponsorship needed in the previous TRL.

Communication between the various project teams, both within the organization in charge of the development of the project and the organization that will receive the development, needs to be fluid and understood at different levels. Many of the failures in technology transfer start at this level, so a project management approach must be implemented to help solve the problems that may arise in using the prototype or understanding the development and testing process for the final application. This demands high technology expertise (development and implementation) of the people involved in this process should be high and commensurate with the project's needs.

Following the design of our concept with AM technologies, the next step that fits this level is the part's manufacturing. AM printers are expensive devices that people with specific knowledge can only operate. Furthermore, the necessary facilities for powder handling, cleaning, and measuring the part are not easy to obtain due to their high cost, so this process must be done in an R&D centre or KTTO with this capability or in a company's AM lab.

TRL 6: System/sub-system model or prototype demonstration in a relevant environment.
The result of the TRL 5 is a piece, a proven concept, a representative model, or a prototype ready to be tested for a technology demonstration in a relevant environment. This environment depends entirely on the developed concepts and is also aligned with the project's cost.

The demonstration may represent a natural system application, or it may merely be a close representation of the intended application while using the same technology. This task demands new technologies to be involved in the demonstration. Due to that reason, this activity should be carried out on specialized facilities only available to formal R&D organizations, KTTOs or corporate laboratories. However, it should also involve formal sponsorship needed in the previous TRL because of the increasing costs. For example, according to Mangkins [71], this activity should be carried out by appropriate formal projectized organizations that can successfully manage the objectives within the time, cost and scope required.

For our concept developed with AM technology, which at this level is a satisfactorily manufactured component that fulfils the manufacturing requirements, it is now the time for it to be further tested. At this level, the piece's porosity, traction, roughness, fatigue, and hardness analysis should be completed to prove that it is in line with the requirements to be installed on the final assembly.

TRL 7: System prototype demonstration in the expected operational environment.
The main objective of TRL 7 is that the system, component, prototype, or model completes a demonstration in the expected operational environment. At this level, the component should be near or at the scale of the planned operational system, and the demonstration must occur in the actual expected operational environment. This is done to assure the system engineering and development management confidence, one step further than the purpose of technology R&D. Once again, this activity can only be carried out in specialized facilities only available to formal R&D organizations, KTTOs or corporate laboratories, but should also involve some of the formal sponsorship needed in the previous TRL. Moreover, it should be carried out by appropriate formal projectized organizations that can successfully manage the objectives within the time, scope, quality, and cost requirements.

In our example of the tested prototype, the activities that should be carried out at this level to meet the objective are the analysis of the components under simulated operating conditions, such as temperature changes, currents through the part, and vibrations experienced, among others.

TRL 8: Actual system was completed and 'qualified' through tests and demonstration.
Once the technology reaches this level, the system development of most technology items is done. Once the prototype has been demonstrated to meet the system's criteria, decisions may be made to incorporate it into an existing system or to construct a completely new system based on the prototype. Naturally, these specialized tasks and decisions can only be made at appropriate specialized facilities available to formal R&D organizations, KTTOs or corporate laboratories. However, they should involve some formal sponsorship needed in the previous TRL. Furthermore, it should be carried out by appropriate formal projectized organizations that can successfully manage the objectives within the time, scope, and cost requirements.

For our example of the component manufactured by AM Technologies, at this level, our prototype has passed the various safety and performance tests carried out at specialized sites close to or like the last factory where it would be produced.

TRL 9: Actual system flight proved' through successful mission operations.
All technologies successfully being used in existing systems in any industry have passed the TRL 9. At this level, once the prototype has passed all tests and proved that it can be safely integrated with the system and will fulfil the performance requirements, it is installed and tested under operational conditions. This operation can generate new sets of

bug-fixing processes not identified previously by the team in charge of the development. However, this bug-fixing should be manageable if all previous TRLs were passed.

Finally, in our example, the component designed and manufactured utilizing AM technologies can be safely installed on the final planned system, and the bug-fixing process should start.

Despite the success of the TRL classification, some authors state some issues regarding the use of the tool. Sauser et al. [72] stated that the tool *"does not include any guidance for the uncertainty that may be expected in moving through the maturation of TRL or that it does not compare with any other alternative to TRL"* [73, 74]. Further descriptions were needed to clarify the scope of each level due to the original description of the tool was considered vague, causing ambiguity in the understanding between the researchers, management and potential program users.

The central and somewhat restrictive aspect that has led to significant developments and expansions in the use and description of TRL is that it is concerned only with assessing the maturity of individual technology, leaving aside where that technology is located within a more extensive system or how it integrates with other technologies. The TRL scale was enhanced further in 1995 with the articulation of the first definitions of each level, coupled with examples to help with comprehension [75]. Despite its relative success, the Department of Defense of the United States introduced the concept of Manufacturing Readiness Level (MRL) to streamline technology transfer in more dynamic manufacturing and to expand the original TRL to incorporate concerns about production and risks associated with time and manufacture of parts, components, systems, and technologies.

The MRL is a metric that ensures that the development of engineering, design process and the maturation of technology can be associated with a manufacturing process facilitating a quick and easy transition and communication with the stakeholders involved in the project.

2.2.2.2 About project management for Technology Readiness Levels 5 to 7.

Developing new technologies often depends on the previous success of advanced technology research and development efforts. The correct use of the TRL classification can also be helpful not just to know which skills have been acquired but also to know if these skills can be used not only in a specific project but also in different projects.

These developments inevitably lead to four significant challenges in each project, performance, quality, schedule, and budget. First, with a correct risk analysis, advanced technology development projects reduce the uncertainty in the so-called 'Iron Triangle'. With such measures, project progress may be improved by cost overruns, schedule shortfalls, and the gradual erosion of initial performance goals [75]. The challenge for PMs is to determine technology readiness and risk assessment in a clear and well-documented way and to be able to do so within the precise stages of the project life cycle.

As mentioned by Mankins [71] for TRL 5 onwards, a projectized approach is necessary to manage the project's development effectively. At this point, a previous estimation of the objectives pursued in terms of cost, time or scope/quality can be stated. The majority of project development risks start during these stages because the project has now entered an experimental phase and has left the research phase behind.

Time and cost control within R&D projects has been a constant concern for companies, governments, universities, KTTOS, research clusters, and researchers. The pace with which a concept develops and the expenses associated with project development is easier to regulate in contexts where time, objectives, and costs can be specified nearly from the beginning. However, in R&D, even when the time or cost constraints are exceeded, the project can be considered a failure.

To increase the uncertainty in R&D projects, even if time, cost or scope are fulfilled, only sometimes the quality of the research is adequate for the result of the project, or the different activities carried out during its life cycle. Keeping track of all the stages and activities carried out in the project is one way in which the quality of the project's outcome can be, and again, only in some cases, considered a success. However, a further problem arises from this, measures of success of R&D projects are associated with many internal and external factors that go beyond the iron triangle, as explained above.

On the other hand, the organizational strategy of universities and KTTOs in terms of developing research lines, participation in projects or searching for alliances with companies are decisive points for their continuity. Therefore, the definition of KPIs for an organization that carries out high TRL projects is vital for both the projects' success and the collaborations' success.

For these reasons, a common understanding of project control metrics, fluid communication, as well as defined criteria that determine the success of a project and quality assessment throughout the project, and the KPIs of the organizations carrying out these projects (on the understanding that companies have previously defined and actively monitor their own KPIs) is vital in order to delineate a suitable project management methodology for R&D projects and the success of the technology transfer process on this TRLs.

2.2.3 Project management metrics and Key Performance Indicators for R&D projects.

The EU's attempts to accomplish the digital transformation of the economy have gained strength to regain the privileged position in the world that it held years ago. Industry 4.0, the solid technological bet made by Eastern countries in collaboration with China, and the increasing pace of innovation in economies such as the United States, combined with the economic crisis caused by the Covid-19 pandemic, will leave in the coming years the most significant investment in R&D in modern history. [1]. Funds that will reach local

[1] EUR 24 billion worth of non-repayable grants from the EU: Polandś most extensive cohesion policy programme approved by the European Commission - shorturl.at/tACNR

governments to support the transformation of their economy by supporting technological projects led by industry in collaboration with universities.

Due to the current environment and the amount of funding available for their implementation, it is essential to regularly monitor how these resources are used for the projects' development and the outcomes produced by UIC. However, since the beginning of the 1990s (with the first study carried out to measure the performance of projects carried out in a UIC [76]), few other attempts have been made in this area despite its importance for the entities involved and policymakers.

Furthermore, digital transformation and development of highly technical projects are characterised by being part of a highly interconnected set of subsystems with high costs, produced at a low volume, that require comprehensive and profound knowledge and skills, involving multiple collaborators and maintaining a continuous integration between the customer and the supplier.

Nowadays, a fully structured and widely accepted system of indicators is still needed to evaluate the results of the UIC [77]. A first attempt to measure the performance of collaborations for implementing R&D programmes and projects, together with a method for measuring it, was made by Fernandes et al. [26]. On the other hand, the study is based on the creation and development of a theoretical technique but needs an actual demonstration or validation. Perkmann et al. [78] identified four stages of UIC, developed a success map explaining how these collaborations work and identified cause-and-effect relationships for their success. In addition, a set of performance indicators was proposed for each collaboration stage.

Current project management tools and techniques have proven inadequate and insufficient for monitoring the development of highly technical and R&D projects. If these are not faithfully controlled and measured during the project life cycle, they can act against their standard development [79]. Additionally, innovation must be evaluated using a wide range of indicators because it is a multidimensional and complex notion that does not fit with typical measurements [80]. Additionally, the complexity of innovation increases with the heterogeneity of the parties involved in a UIC, as we have already described in the contextual perspective of this type of collaboration (2.2.1.1).

Some research suggests that measurements can be beneficial for innovation, arguing that these measures can help managers to control tasks, processes and outcomes, ensuring that innovation is well-supported and carried out efficiently. For example, Browning & Ramasesh [81] concluded in their research that many existing models focus more on the activities performed than on interactions or project deliverables because humans tend to pay more attention to activities that can be measured, and that can lead to a concrete result.

Another research line suggests that measurement can dissuade managers from seeking to deepen innovation and obtain more innovative results as a short-term reward. According to several studies, innovation measurement hinders innovation by pushing organisation members to concentrate their attention too narrowly and lose sight of the broader focus that it should have.

What should we do? Which way to go? Experience dictates, regardless of the environment we are talking about, that what cannot be measured cannot be improved. However, there is a balance to be struck. Too much measurement during the project life cycle can be detrimental to the normal development of the project, especially when these projects are developed in SMEs or small project teams or are managed by PMs who do not have the appropriate or necessary experience to manage and perform these measurements, as the excessive paperwork around the work can be overwhelming for both the PMs and the project team, which is why, for example, traditional project management methodologies cannot be applied to all types of projects, and neither do all project teams.

In general, process or performance metrics to measure the maturity of new technologies and systems have yet to be fully developed. Currently, the techniques and tools available, such as Quality Function Deployment [82], Concept Selection Process [83], First Requirements Elucidator Demonstration (FRED) [84], Integrated Design Model [85], Subsystem Tradeoff Functional Equation [86], Design for Manufacturability [87], Design-Build-Test Cycle [88]. Periodic Prototyping [89], cost as an Independent Variable or CAIV [90], and Lean Product Development Flow [91], are fragmented and not used consistently throughout the process [92].

It is difficult to establish control mechanisms that can effectively affect the development of highly technical projects and R&D projects due to the lack of process metrics, high unpredictability, reliance, and lack of consistency [93].

However, can the management of R&D projects be measured? Understanding the limitations and unique characteristics of this type of project and the development of this thesis project, we believe it is possible. Some companies believe the same and measure some aspects of the process. On the other hand, researchers have also discussed the same question and have contributed to the scientific literature by debating what kind of measurement is beneficial. Still, after decades of research, the conclusions are mixed and need clarification.

Having processes for planning and monitoring projects is necessary to guarantee the success of the efforts made on R&D. Cooper & Kleinschmidt [94] concluded in their research that project plans, task scheduling, monitoring, and feedback are among the ten critical factors for the successful development of a project. Dvir & Lechler [95] concluded that efficiency (schedule, money, and scope), perceived value, and customer satisfaction are all positively impacted by the planning quality. Pinto & Mantel [96] found that for R&D projects, inefficient scheduling of tasks is strongly related to failures in the implementation processes and that both monitoring and feedback can impact customer satisfaction. Furthermore, the lack of an appropriate plan makes it difficult to control the development processes that can lead to cost overruns, delays, or failures in project implementation as has already happened in some government projects, R&D efforts [97] and new product development [98].

Maintaining a comprehensive picture is especially crucial during the early phases of developing an R&D project when uncertainty is still high, but corrective measures may still be addressed. PMs must apply this approach to the project to enable them to measure the process and control the development of the system through proper planning, scheduling, and monitoring [79].

In this research, we will focus on three aspects to understand this holistic view of managing and controlling an R&D project, the study of KPIs, Project Success and Earned Quality Method (EQM).

2.2.3.1 Key Performance Indicators.

At the organisational level, the development of measurement systems is necessary to set objectives and monitor the effectiveness and efficiency of the use of resources. Commonly, these metrics take the form of KPIs, which provide an objective criterion for forecasting, measuring and planning the activities carried out in the company. It should be emphasised, though, that performance metrics' goals, definitions, and contents differ. Since they must fit the competitive environment and strategy, many approaches are utilised to design and choose business KPIs [11].

Within the scientific literature, it is possible to find several descriptions of KPIs categories. Cortes et al. [99], identified five strategic categories for KPIs:

- Cost;
- quality;
- flexibility;
- stock;
- lead time.

With these categories, there is an intention to capture the organisation's strategic objectives and enable alignment with tactical, strategic, and operational performance. For example, Toor & Ogunlana [100] found different authors who included customer and stakeholder satisfaction as project success criteria in addition to the traditional iron triangle (Time, Cost, Quality).

Within projects, Kerzner [101] identifies time, cost, resources, scope, quality and activities as critical metrics for project management KPIs. For example, Toor & Ogunlana [100] enhances the project team's capacity to control project risks and find solutions to issues that arise during the project life cycle to evaluate the project's success. Technical efficiency of execution, management and organisational implications, staff growth, partners' technological capabilities, and organisational performance is also considered in measuring project success. However, when using these fancy metrics, conventional metrics such as cost, schedule, quality, and security should be addressed [102].

When discussing the integration of KPIs in organisations, Toor & Ogunlana [100] highlight operational, life cycle, strategic and socio-economical aspects. The author also assures that the criteria for measuring the success of projects should be based on strategy, sustainability and security.

On the other hand, Dombrowski et al. [103] proposed specific criteria for a performance indicator measurement system in the context of product development. These criteria are:

- Aligned with the organisation's strategy;
- data quality (based on the validity and timeliness of the data);
- compatibility with the hierarchy;
- capacity to adapt to changes;
- relevance;
- visualisation;
- effort.

In addition, Kerzner [101] describes six key characteristics for project-oriented KPIs:

- That they are predictive (an eye on the future);
- measurable;
- actionable (correctable);
- relevant (relation to the success/failure of the project);
- automated;
- that they are few (the necessary ones).

According to several researches [100, 104, 101], KPIs are associated with the success of the project in the context of KTTOs, which are by nature project-based organisations. The measures on which the success or failure of a project is judged are the success criteria, and the KPIs are the factors that constitute these success criteria. These KPIs are crucial for project management, as they allow monitoring of the progress of projects. However, it must be ensured that the proposed KPIs are aligned with the organisation's strategy, that stakeholders are taken into account, and that short and long-term benefits are covered [104].

Measuring the performance of R&D projects and knowing whether a project is successful in project-based organisations has become a fundamental concern for PMs and managers of organisations. As a result, the question has been extensively debated in the literature without a resolution as it is difficult to determine whether an R&D project would be successful or not [105] and depends not only on what criteria they are evaluated under but also on who carries out this evaluation or when it is carried out, as well as the fact that if a project can reach its maximum performance, this is no guarantee that the project will be successful.

The concept of performance measurement of a project involves the identification of metrics and their methods of calculation following the organisation's mission, vision and quality manuals. Cruz et al. [11] proposed a model identifying, measuring, understanding and controlling a series of KPIs for project-based organisations through a Lean Approach. However, although several indicators were proposed, the research needed more practical measures derived from implementing these indicators.

Beyond the lack of commitment to KPIs that may arise, a huge issue is the lack of consistent use since many PMs may find them irrelevant or inadequate to ensure the need for existing control over project development. It was evident that projects frequently have multiple dimensions and that the priorities of various project members differ. Therefore, it is necessary to consider many factors in addition to the fact that the project's success may change over time depending on the interests of the stakeholders [106].

However, the ability to integrate the KPIs established in project-based organisations into components that can be assessed and managed in the projects that the organisation undertakes is essential for our research. In this way, the construction of a KPI result is not only fed by a set of elements (such as the overall result of a project portfolio). However, it can be detailed and adjusted to each of the projects undertaken by the organisation.

A properly constructed Balanced Scorecard, and a correct definition and classification of KPIs (e.g. following the method described by Cruz et al. [11]), can help to visualise, analyse and make decisions at the organisational level, but aimed at improving project performance.

2.2.3.2 Project Success.

We have been discussing this Theoretical Framework to project success. However, this term still needs to be discovered for general understanding. Two distinctions must be made at this point. First, De Wit [107] and some other researchers distinguish between Project Success (measured against the achievement of overall project objectives) and Project Management Success (measured against traditional measures of project performance concerning cost, time and quality). The second distinction to be made at this point concerns the difference between Success Criteria (the measures by which the success or failure of a project will be judged) and Success Factors (those inputs of the management system that can be modified independently and that contribute either directly or indirectly to the project's success. If they exist, they must be identified and analysed to see whether they can be strengthened and enabled to reach the level necessary for success [108].)

The definitions described here will be used throughout the document. Then another essential aspect of being understood is distinguishing between project success and performance. On the one hand, performance must be measured and tracked throughout the project life cycle, whereas project success can only be evaluated once completed. On the other hand, a project monitoring and control system must consider both aspects, ensuring that measurements of project performance give accurate clues as to the prediction of project success.

Finding and adequately evaluating project success is one of the top concerns for PMs; therefore, the topic is widely argued in the scientific literature as the core of project management and the elements that influence it. However, our understanding of project success has evolved with different points of focus, starting with the understanding that if the outcome of a project had good technical performance, it was successful. Then, in the 1970s, the concept of the iron triangle (Time, Cost, Quality) came onto the scene, and projects were evaluated and their success assessed against these criteria. However, in the 1980s, one of the main actors that had been primarily forgotten became the one who would decide whether a project was successful or not, the criterion of customer acceptance. In the 1990s, another new leap was made. The project was no longer considered a one-off activity carried out in a company but was evaluated according to its impact on the organisation and the surrounding environment. To assess if a project is successful, we must incorporate all of these perspectives (technical performance, project management metrics, client acceptability, and organisational and cultural influence).

In terms of R&D initiatives, gauging project success has grown in importance for managers and executives in recent decades, leading to extensive debate in the literature [11]. However, figuring out whether an R&D project is successful is challenging because obtaining optimum performance only sometimes entails success.

Success management can occur on multiple levels, with each level complementing the others to the top. Furthermore, the operation has a role in the success of the organisation's project portfolio; thus, the entire picture must be handled. Because the diverse elements of the puzzle must be balanced, the success of each level is decided by the defined success criteria and may be somewhat complementary in practice.

Another element that makes measuring the success of projects particularly complex is that it also depends on the time at which it is evaluated [107], there are not few cases in which a project is considered a failure once completed, but as time goes by, the perception changes and what initially seemed like a bad thing ends up a meeting or even exceeding initial expectations [109, 110]

Because the conclusion may be successful, but the anticipated benefit may not materialise, project success cannot be categorised as "success" or "failure". Furthermore, a project that is prematurely ended because it is no longer viable, desired, or valuable due to environmental changes cannot be regarded as a failure [111]. As a result, if the areas at the assessed level are perceived as failing, it is critical to identify the underlying causes, which may be planning failure (the difference between what was planned and what was achieved) and actual failure (the difference between what was achieved and what was achieved) [112]

Because each project is unique, particular criteria are required to credit its uniqueness. However, general success and failure criteria allow projects to be compared [113]. However, as different stakeholders' definitions of project success may differ, it is necessary to define and document each stakeholder's definition of project success as well as who, when, and how to measure it [114]. Project management, project activities, output, outcome, benefit, and business value should all have success criteria [115]

Criteria must be defined in advance, reviewed, and adapted to the changing project environment to measure success effectively. These processes must be taken into account through formal change management processes. For example, even premature project closures might be viewed as a success because no resources are spent [10]. On the other hand, the outcome of a project's evaluation of its success can vary significantly depending on the perception of the stakeholders or the PMs. While it may favour one stakeholder (internal or external), others may perceive the outcome against them and find it unsatisfactory based on the planned perspectives and with the interests and objectives set out initially [116].

A common tactic is to break success down into measurable units of project success, and project management success [117]. Other techniques differentiate further and employ other components, such as product and commercial success. While project success is tied to project objectives, product success is related to the requirements. It is also *"reflected in the use, satisfaction, and effectiveness for the benefit of the intended users"* [113]. The business strategy determines success, which is accomplished when the funding organisation realises the promised benefits through the project means outlined in the benefits management plan.

However, reducing the complexity of measuring, identifying and controlling these success criteria is one of the primary research focuses in the coming years. The approach we take in one of the publications from this Thesis [10] has to do with grouping the success criteria into dimensions previously selected from a literature review, then ensuring with both project team members and stakeholders that the chosen criteria are relevant, applicable and measurable; and thirdly, asking stakeholders and the project team which of these criteria they consider most important when carrying out and evaluating a project. This provides information on how the success of public-private R&D collaboration projects are evaluated.

Another crucial point to keep in mind is that, when discussing KTTOs operating between TRLs 5 and 7, in order to assess a project's performance or success, it is necessary to not only observe how it is developed but also to monitor what happens after the results are given to the organisation and to examine the technology transfer process. Only in this way is it possible to compare the initial expectations of the project with the results obtained. Therefore, the management of these collaborative research programmes and projects will benefit significantly from a response to the need to measure and monitor the results of collaborations.

Utilising the Earned Quality Method (EQM) is crucial to monitoring the outcomes of these collaborations and the projects being worked on. This method, described initially by Paquin et al. [3], proposes that the construction of the final quality of a project is based on the recurrent and cumulative evaluation of the results obtained during the development of the project. Thus, beyond measuring the project in terms of meeting objectives such as time, scope or cost, the methodology seeks to ensure that the result has a quality evaluated by initially defined success criteria that guarantee that the final result meets the initial requirements.

2.2.3.3 Earned Quality Management in project management.

Traditional project management methodologies make it possible to measure and control deviations in terms of cost and time. Hence, PMs focus on achieving the objectives set in these two aspects, as these are where they have the most data available as the originally planned activities are completed. Unfortunately, it is impossible to have complete control over cost and time when it comes to R&D initiatives because there is no certainty that the project will produce the desired outcomes. As previously said, organising the activities in an R&D project from the beginning is more significant than the internal process of carrying out these activities since it aims to establish a shared framework for how the project will be conducted. This planning should be done based on experience gained in terms of knowledge and data from previous projects. As the project progresses, the data will allow the PM to review the scheduling of future tasks and reschedule the use of resources or tasks as necessary.

On the other hand, the performance measures carried out in the project aim to inform about the status of the activities continuously, which facilitates the achievement of the objectives and final results set by the stakeholders, as well as allows early decisions to be made about when changes should be introduced in the execution of the project or the objectives.

One of the essential components contributing to the success of R&D projects is proper project planning and control through task scheduling, monitoring, and assessment [95]. However, these classical planning and control tools focus on measuring specific aspects of the project, such as tasks completed, cost or time spent on completion, which are essential for some stakeholders, but which, in the case of R&D projects, are inadequate to show whether the project or technology is being developed properly according to the project life cycle. The project approach may become hesitant if these factors are only measured, and the project's overall goals may need to be remembered in the process.

Classic project management practices and methodologies recommend using specific techniques and tools to monitor the efforts to achieve a project. Gantt charts, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), Critical Chain Scheduling (CCS) and Earned Value Management (EVM) are widely used tools that, with their advantages and disadvantages, have been proven their effective.

In the case of EVM, it is a well-known project management system that integrates cost, schedule and technical performance, which allows the calculation of cost variances and schedules, performance indices, and the prediction of project cost and schedule duration. On the other hand, it provides early information on project performance to highlight the need for eventual corrective actions. Throughout its history, this system has been extensively employed. For instance, the US Department of Defense used EVM as a reaction to process cost overruns, delays in task completion, and project objectives that were not met. Within two years of its implementation, cost overruns on significant weapon system development projects were cut by as much as 95%. [118].

However, applying a classical methodology for R&D project management, or even using EVM, is ineffective in this type of project because a precise breakdown of all project tasks is needed for this tool to work. This is very difficult to do, as the tasks necessary to achieve a goal may be set late in the project life cycle if there is no information with historical data on the tasks performed in similar projects. Therefore, it is particularly challenging to establish a meaningful project cost baseline when the project objective cannot be stated concisely and uncertainty is introduced into the task descriptions and the time required to fulfil them [79].

Several researchers have criticised the EVM's two-dimensional approach (Cost and Time) over the years, which has led to the development of strategies and methodologies that aim to increase the methodology's scope of action[3, 119]. The management of a project, especially an R&D project, encompasses dimensions that go beyond time and cost to achieve the project objectives; therefore, the integration of other project dimensions, such as quality, sustainability or technology, would be beneficial to have a broader approach in the management of this type of project.

The successful implementation and evaluation of a project, which is comparable to the proper completion of project tasks and also happens to be the project's main goal, have been claimed to depend partly on quality [119]. Some research has recently attempted to broaden the EVM approach, such as Rozenes et al. [119], Lauras et al. [120], or Hazir [121] among others.

As discussed, quality is an integral part of the "iron triangle" of project management, so, naturally, integrating it as an additional dimension of EVM is being studied by project management practitioners and researchers. Paquin et al. [3] have been among those who have ventured down this path. Their study proposed the Earned Quality Method (EQM) that integrated quality into EVM through the Quality Breakdown Structure (QBS). Later, Rozenes et al. [119] used Data Envelopment Analysis (DEA) to integrate the Multidimensional Project Control System (MPCS) with the Earned Value Management System (EVMS). Besides them, Solomon & Young [122] suggested a system called Performance-Based Earned Value (PBEV), which integrates product quality requirements into EVM. Also, Pollack-Johnson & Liberatore [123], based on the study by Paquin et al. [3], incorporate quality considerations into the analysis for project time and cost trade-offs and as an aid to decision making, showing how the models they develop in their research can be used to generate quality contours to illustrate the trade-offs between time, cost and quality.

The concept of a quality function for individual tasks was introduced by Liberatore & Pollack-Johnson [124] in a continuation of their research and used the bivariate normal functional form (after also evaluating a bivariate logistic form), which was incorporated into a mathematical programming model that enables quality to be explicitly taken into account in project planning and scheduling.

As briefly mentioned, by using EVM to evaluate the quality of project deliverables, Paquin et al. [3] addresses the quality dimension of a project. More specifically, they assume that quality is a measurable construct and provide quality with the ability to be built up cumulatively during project implementation. The EVM concept is applied by initially determining the expected final quality and breaking it down into quality attributes that are then associated with particular project activities, thus creating a quantitative link between the performance within the project and the resulting quality and allowing quality objectives to be monitored.

It was the method of Paquin et al. [3], which introduced the concept that quality is a measurable concept that is progressively built up over the life cycle of the project, from which several methodologies have been derived ([125, 126, 127, 128, 129, 130]). However, they have yet to be directed towards R&D projects. Only Schuh et al. [129] used the principles set out by Paquin et al. [3] to assess the effects of deviations in activities on the objectives of a development project.

EQM has several features that make it useful for use in R&D projects. For example, it allows PMs to elucidate and structure customer needs and expectations as it decomposes overall customer satisfaction into a hierarchical structure of quality criteria. Furthermore, according to the principle that quality is achieved progressively throughout the project, the method can aggregate lower-level quality criteria into higher-level quality objectives. On the other hand, the method provides a method for evaluating the planned and earned quality of the project deliverable throughout its life cycle. Because the quality criteria, which were jointly established by the PMs and stakeholders and against which the project activities are evaluated, are achieved gradually and cumulatively as the project is carried out, making it easier to estimate the effort required to complete them. Additionally, it offers measures of quality deviations. Finally, decisions on the trade-off between quality, time, and cost are made more accessible in this way [131].

In order to successfully carry out an R&D project, the PM must initiate an interactive, flexible and responsible control of the project plan, task scheduling, monitoring and evaluation from the beginning. The plan should be carried out in a manner that is consistent with the expected project results, should not be unduly constraining, and must be based on milestones. However, as Magnaye et al. [79] conclude, there should already be a high level of control over the process during the development of the early stages of the project, as well as a greater emphasis on the application of the chosen process metrics and lessons learned, in order to identify problem areas and address them quickly. So, thanks to the research that has been going on, the EQM approach is a suitable approach to manage this type of project because of the characteristics we have already mentioned.

However, there are several aspects to be taken into account when applying EQM to a project:

1. It is necessary to guarantee that the project's progress is shown graphically;
2. the evaluation of the quality of the tasks is subjective, so it is necessary to explore objective techniques and measures agreed upon between the PMs and the stakeholders that allow absolute clarity on the partial and final results of the project. Again, communication plays a significant role in the management of these projects;

3. time and cost are not taken into account in the EQM, but knowing the project's quality criteria in advance, and having a comprehensive understanding of it, enable PMs to explain what efforts would be required to carry out the tasks and achieve the desired quality; The need for more clarification on determining the quality criteria for assessing the project, according to the study by Paquin et al. [3], is notorious, so approaches aimed at solving this impasse should be implemented. Therefore, the approach and assessment of quality criteria from the point of view of PMs and stakeholders is of vital importance for the success of the project [10] and of the EVM.

2.2.4 R&D Project Management Methodology.

As we have previously analysed, thanks to the policies implemented by some countries to promote and sustain UIC, many academic contributions have tried to explain, understand and justify these interactions in economic terms. However, only a few studies have been conducted to examine the factors that influence both the participation of companies and universities in R&D projects, the characteristics of these projects, and the management methods used in these projects.

We must begin with the fact that the discipline of project management is constantly evolving in response to the projectification of societies and to the needs, uncertainties and changes that arise from year to year, which means that the validity and timeliness of the methodologies and practices developed are quickly being left behind. Now, speed and agility are characteristics demanded from project teams and managers as requirements for implementing the various technologies that make up the fourth Industrial Revolution. All this has led to continuous changes in standards, methodologies, practices and methods related to project management, to maintain and increase project success rates.

However, there are two crucial aspects to take into account. Firstly, the management of the UIC differs from the management of the UIC projects; while for the first aspect, the contractual clauses for managing the results and intellectual property rights, the trust between the parties or the experience of previous collaborations, are some of the characteristics that determine these collaborations; for the second aspect, the management of R&D projects depends entirely on the organisations, their PMs, and the approaches used in the methodologies.

Using classical, agile or hybrid methodologies brings different advantages and disadvantages to the project. There still needs to be a standard methodology in the literature to apply to this type of project. The term "one size fits all" does not work in project management. However, a first effort was developed by the European Commission, which in 2016 launched the first edition of the PM^2 [132], a hybrid project management methodology applicable to any project, and developed taking into account the needs, culture and constraints of the EU to deliver solutions and benefits to organisations effectively managing work throughout the project life cycle. This could be classified as the first methodology created and approved by a governmental regulatory body to manage UIC projects internationally. However, some shortcomings in terms of the adaptability and lightness of the documentation or its lack of practicality when it comes to digitisation and virtualisation have meant that its dissemination and use have not spread to the level initially intended.

Naturally, this raises the question, "And if the regulator, who is the one setting the restrictions and requirements, does not have the answer to the question of how to manage projects best to meet the needs they create, then where can we find it?" Unfortunately, there has yet to be a satisfactory response to this question.

Although project management, by its nature, tries to focus on controlling and minimising the risk of a project deviating from the developed plan and not achieving its objectives, this is not easy to achieve. Project management involves two aspects: planning a new 'enterprise' and executing its execution. For the former, according to the PMBOK [133], the main elements to control are time, cost, quality, resources, communications, risk and procurement. For the second aspect, informed decision-making and plan adjustments according to needs are some of the most relevant features.

According to the PMBOK definition [133], a project management methodology is a system of practices, techniques, procedures and rules used by those working in a discipline, such as PRINCE2, Scrum or Kanban. In addition, project management methodologies, in general, are based on carrying out a series of activities in a specific order and applying knowledge, skills, tools and techniques to it, trying to make the most of the technical and human resources available to meet the project's objectives. Adequate project management is the one that occurs when project planning allows foreseeing and correcting in time the most significant number of unforeseen events that may arise. However, in an R&D project, the research results may differ dramatically from what was anticipated at the beginning but are still beneficial to the organisation—because of this, applying traditional or exclusively agile methodologies to this kind of project is complex.

The academic literature stresses the importance that an adequately constituted monitoring and control methodology for an R&D project should focus on the maturity of the technologies, the integration elements and the system as a whole. On the other hand, they agree on the need to maintain a non-linear structure and the idea that detailed planning at the beginning of the project is a challenging and unfruitful task without the right tools. Thus, phased life cycle approaches are necessary to visualise the project management process. A non-linear approach must be defined to allow more creativity, flexibility and changes in the overall ideas. To overcome the dynamic scope and deal with changes, the initial planning, the definition of the methodologies and technologies employed, and the requirement for an incremental and iterative research phase are all crucial.

An R&D project management methodology should be flexible, define milestones based on research maturity or product development, be interactive, and be able to respond and adapt to changes in technology and requirements. This can be facilitated by an interactive project management methodology that promotes congruence of objectives and enhances learning by creating an information infrastructure with process performance metrics linked to the organisation's strategy.

Various methods have been discussed and developed to manage R&D projects. Phased Project Planning (PPP), a control mechanism for new product development, was introduced by NASA to ensure that projects are executed according to plan and delivered on time. However, this engineering-based approach needs to be faster and more bureaucratic [134]. Cooper then presented the stage management system approach [135], focusing on quality and requiring that each stage's inputs and outputs be evaluated, tested, and approved before going on to the next stage to solve these restrictions. Although this strategy limits options for creativity and innovation, a hybrid project management methodology that combines agile and conventional methods is recommended.

The characteristics of a suitable methodology, according to Kerzner [136], include the recommended level of detail, the use of templates, standardised planning, time management and cost control techniques, standardised reporting, flexibility for use across projects, flexibility for rapid development, user-understanding, acceptance, and usability within the organisation, the use of standardised project life cycle phases, and the assertion that it is based on guidelines.

This can be achieved with agile, hybrid or classical methodologies and approaches (to a lesser extent). Agile approaches are now spreading across the discipline, showing signs of improving project success, and are increasingly being used in industries other than software development [4]. Preliminary project results are specified, initial goals are established, and project outcomes are continuously assessed and improved by utilising adaptive procedures in an agile approach. An essential aspect of agile methodologies is the distribution of responsibility among project members and the inclusion of project stakeholders in both formal and informal communications around the project [137].

On the other hand, hybrid approaches have similar effectiveness to purely agile approaches. While accomplishing the same goals in terms of budget, time, scope, or quality, analysis by Gemino et al. [67] revealed that hybrid and agile approaches considerably boost stakeholder satisfaction over traditional ways. For example, a hybrid project management methodology combines practices and methodologies from more than one project management approach, seeking to use the best practices from each approach to improving the overall results of the methodology created.

Regarding the hybrid approaches and methodologies developed, several proposals have been developed in the scientific literature to improve the management of R&D projects. For example, Mikulskiene [20] developed an approach in which these projects were managed in two phases. The first phase, planning, was associated with issues such as human resources, stakeholders, partners and teams. In contrast, the second phase focused on the project's technical developments.

On the other hand, Mosbrooker [66] represented the project management life cycle in four phases, which included separate concepts for project planning, execution and completion. The author further recommended setting abstract objectives, maintaining flexible planning and focusing on constraints and the environment. Kerzner [112] represents the new product development life cycle in five phases: concept development, planning, testing, implementation and closure; it also recommends the overlap between the phases and the division of long-term product development projects into smaller projects.

The six-phase life cycle, which places a stronger emphasis on managing R&D projects, is likewise consistent with the methods mentioned above. Although four-, five- or six-phase life cycles are defined with detailed information, their suitability is questioned as these approaches maintain a non-linear structure, whereas R&D projects cannot continually be developed with linear approaches.

Gutierrez et al. [138] developed a methodology in which they combine classical project management theories and some of the best practices of Scrum. This methodology includes the phases of definition, design, development, testing and release, with an emphasis on rapid customer feedback derived from the Scrum approach in the development phase and control of aspects occurring in the release phase, as well as saving resources through redesign cycles, functionality and usability testing of deliverables during sprints in the development phases. With a similar approach, Cooper [139] represented the Triple A (Adaptive, Agile and Accelerated) approach, a hybrid structure of Stage-Gate and agile approach, which comes from the adaptation of the team to the context of the project, and the agility that occurs during iterations and spirals.

On the other hand, du Preez & Louw [140] represented the Fugle innovation approach, which combines the staged approach with the agile approach. They rely on the innovation process being carried out internally but connected to the external environment and outsourcing, enabling overlapping stages and iterative loops. Sommer et al. [141] also introduced industrial Scrum, combining a staged approach and Scrum. In this approach, the organisational level applies the Stage gate approach, while the Scrum approach is used at the project level.

However, when discussing the creation of hybrid methodologies, the question remains as to how the decision to combine two or more approaches is made. Fijin [142] represented a model in which decision-making on the combination of approaches is facilitated. The linear structure and degree of environmental control are the main axes for decision-making in this model.

According to Werner [143], the status of an R&D project and its improvement potential can be identified by applying an integrated planning, management and control system in the R&D environment. In order to carry out efficient project monitoring and to examine the current project situation, several actors suggest a continuous assessment of sure pre-defined KPIs [144]. The method developed by Paquin et al. [3] directly addresses the challenges of controlling the quality achieved in a product development project. On the other hand, as we have seen, the requirements of each level change, as well as the recommended practices to carry out. It is crucial to know at what point of the TRL the project is carried out to avoid failing to meet the objectives planned in the project. Another important aspect is to understand what project success is and how it is evaluated according to the organisation carrying out the project and its stakeholders. Furthermore, it is vital to know not only how it is evaluated but also how this state of "success" is reached. The analysis of data throughout the project, the ability of PMs to make timely, data-driven decisions, and the completion of deliverables as technology or product maturity levels develop without constraining project teams and managers with stringent processes and demanding and exhaustive documentation will help to meet project objectives and satisfy the various project stakeholders.

Finally, the results of the Gemino et al.[67] study validate practitioners' decisions to combine agile and traditional practices and suggest that hybrid approaches lead the way in approaches to project management.

2.3 Research methodology.

The analysis and understanding of each of the items mentioned above will help to situate us within the conceptual model of the research. The components and interconnections between these topics are described (**Figure 2.3**), with the final objective of the research: the development of a methodology for R&D project management using quality criteria as a performance indicator.

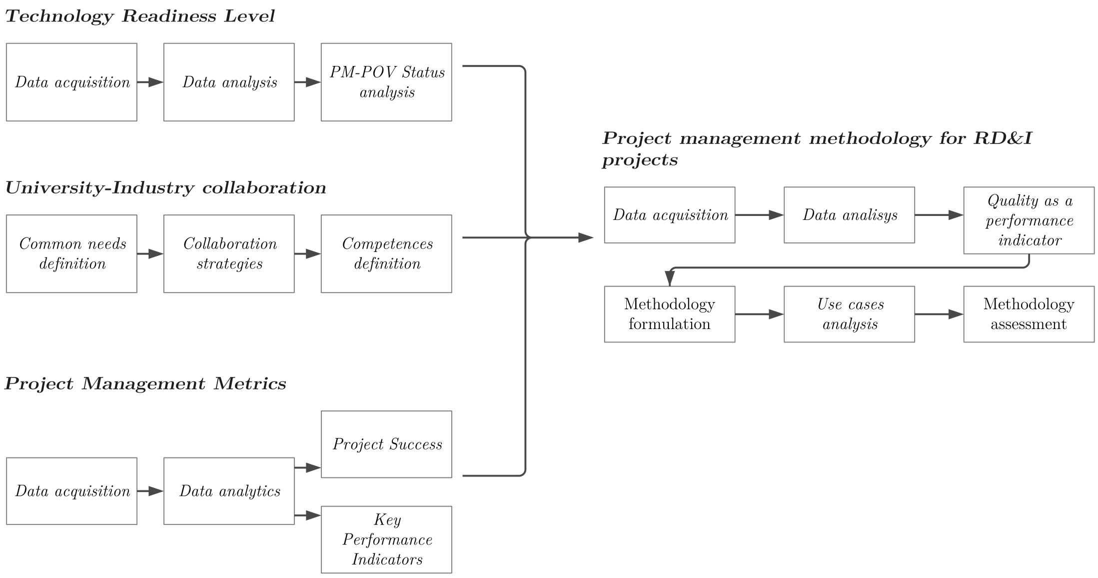

Fig. 2.3: Conceptual model of the research

In each of the publications presented in this thesis, the following data collection methods were used (**Figure 2.4**):

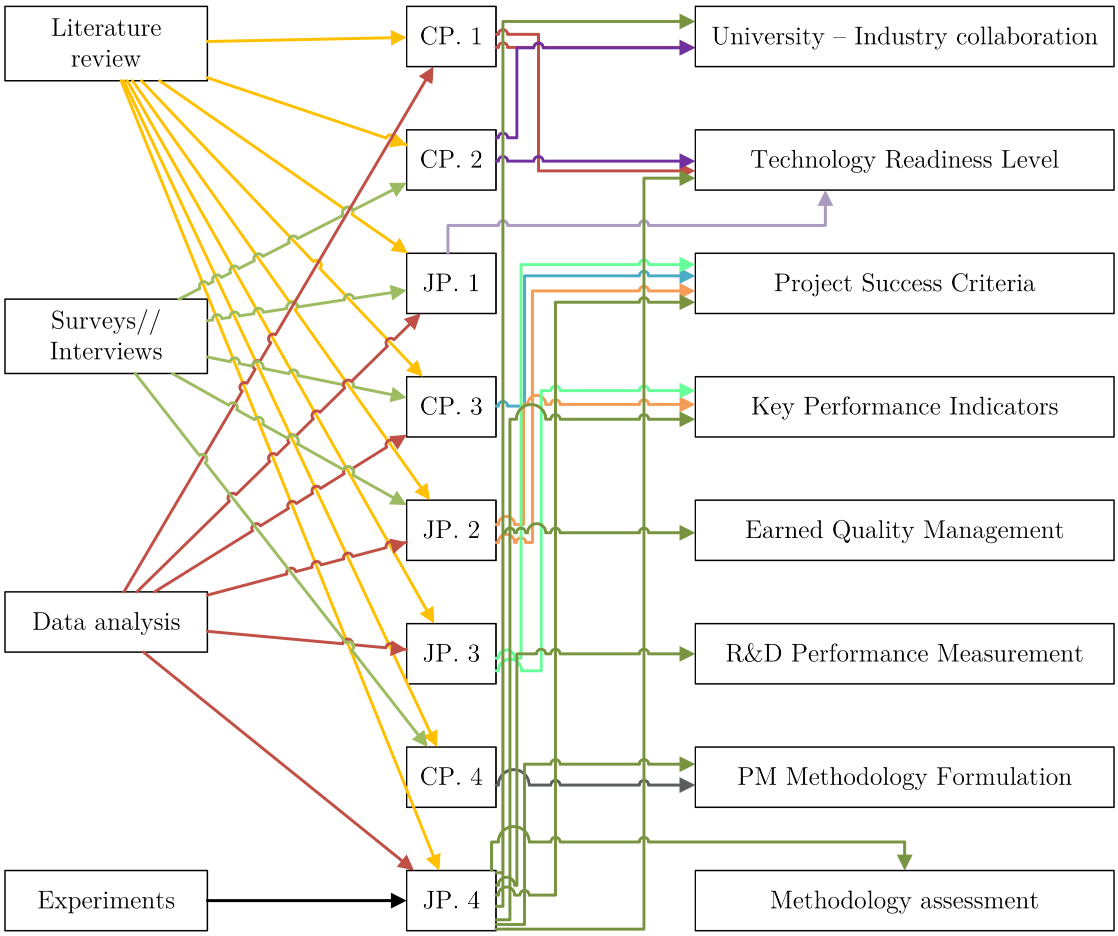

Fig. 2.4: Collecting methods

As seen in the graph above, the research methodology followed in each publication varied, in the **First Publication: "Patterns for International Cooperation between Innovation Clusters. Cases of CFAA and ruhrvalley"** (See Section 6.1 and Figure 2.5) the case study that outlined how the collaboration between the two clusters should proceed was developed as the starting point. A literature review was required to support general recommendations for cooperation, and it was then followed by a systematic analysis of the two clusters to identify any shared characteristics. This analysis then allowed the development of critical actions for the two entities' cooperation.

In the case of the **Second Publication: "Building Cooperation between Innovation Clusters Based on Competences Requirements. Case of CFAA and ruhrvalley."** (See Section 6.2 and Figure 2.6), a series of interviews on these competencies were conducted with three focus groups, divided according to experience, role, and technology knowledge, in which they were asked to identify the competences needed to

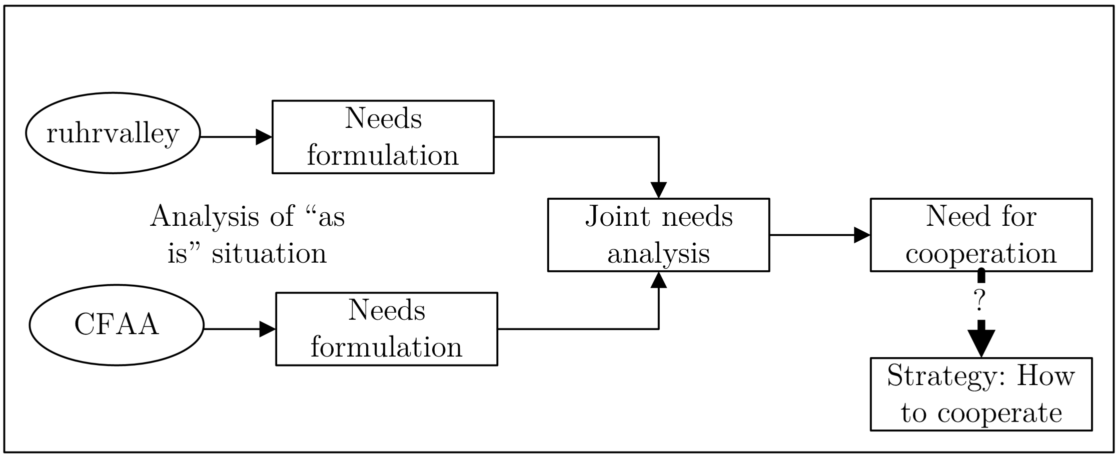

Fig. 2.5: First Publication: ”Patterns for International Cooperation between Innovation Clusters. Cases of CFAA and ruhrvalley” - Research Methodology

participate and manage a collaborative R&D project. Supported by a literature review, they answered the research questions and achieved the publication’s objective.

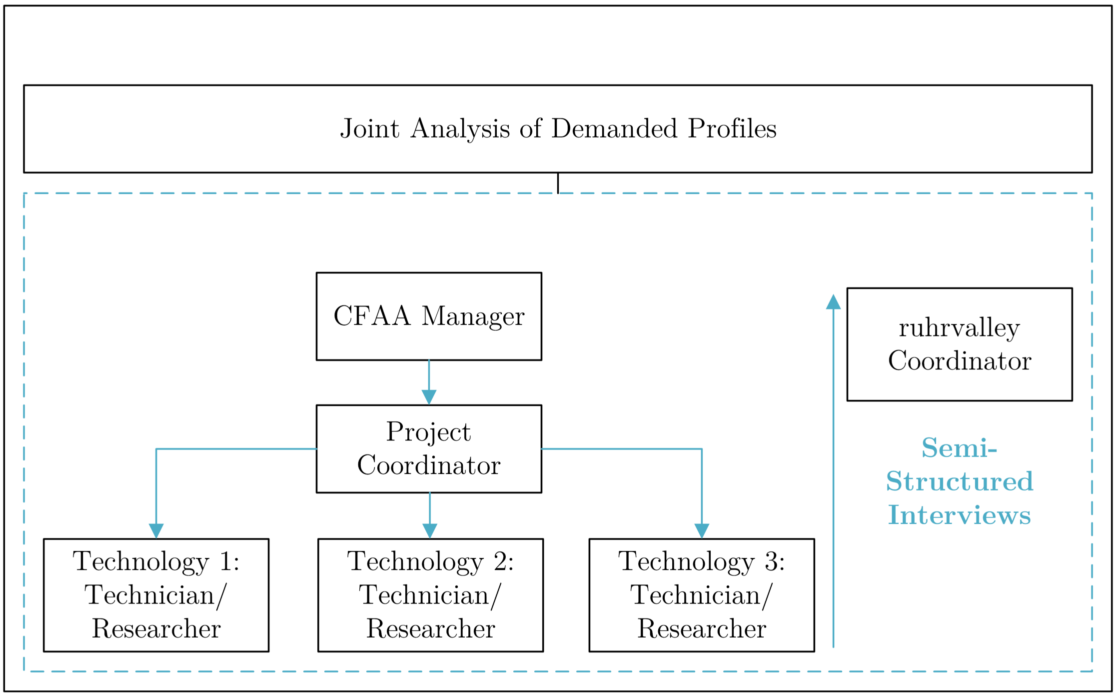

Fig. 2.6: Second Publication: ”Building Cooperation between Innovation Clusters Based on Competences Requirements. Case of CFAA and ruhrvalley.” - Research Methodology

In the **Third Publication: "TRLs 5–7 advanced manufacturing centres, practical model to boost technology transfer in manufacturing."** (See Section 7.1), a benchmarking study on comparable centres in Europe was conducted to evaluate various aspects of scientific capacity, validation of results, research capacity, equipment suitability, technical quality of the equipment, availability of the equipment, and capacity of the same in order to comprehend the context in which a research cluster focused on high TRLs develops. With the data collected, an analysis was conducted and, based on a bibliographical review, a series of recommendations were made to the Basque Country for creating and strengthening this type of centre.
For the **Fourth Publication: "Assessing the success of R&D projects and innovation projects through project management life cycle."** (See Section 8.1), in order to assess the effectiveness of projects completed in a research cluster from the perspective of PMs, a survey was carried out. Based on a literature review, the success criteria for R&D projects were translated into qualitative questions ranked on a Likert scale. The validation and reliability of the survey were confirmed through an analysis performed with Smart PLS software to validate the questions measuring the contribution of each dimension of project success to the success of the realised projects.

With the input of the data analysis, it was possible to identify the most crucial success factors for the research cluster projects and produce recommendations for the project methodologies that would be created in the future.
In the **Fifth Publication: "Project Success Criteria Evaluation for a Project-Based organisation and Its Stakeholders—A Q-Methodology Approach."** (See Section 8.2 and Fig 2.7, a survey was conducted using Q-Methodology (a statistical semi-quantitative technique) in which the PMs of the research cluster and the key stakeholders were asked to rank the previously identified success criteria in order of importance. This survey was based on two research questions, a literature review of the most critical success criteria for the realisation of R&D projects in the context of collaborative projects with public-private organisations and a literature review of the success criteria. Semi-structured interviews were conducted as part of the survey to verify the applicability of the chosen criteria and gather data that would be crucial in selecting the order of the components. A subsequent analysis of the data allowed us to categorise the participants based on the similarities and differences in the participants' perspectives on three factors (groups), as well as to determine which were the most crucial success criteria for this type of project for both stakeholders and PMs in the innovation cluster.

In the **Sixth Publication: "Identification of key performance indicators in project-based organisations through the lean approach."** (See Section 8.3), a Systematic Literature Review (SLR) was carried out with the primary purpose of studying the relationship between project success, lean and performance indicators in a project-based context. The current state-of-the-art was identified and examined, databases to be consulted, and keywords to be included in the search queries were defined. Subsequently, the identified documents were selected according to defined exclusion criteria. Once the documents to be studied had been defined, the publications were analysed using thematic analysis and synthesising the information collected.

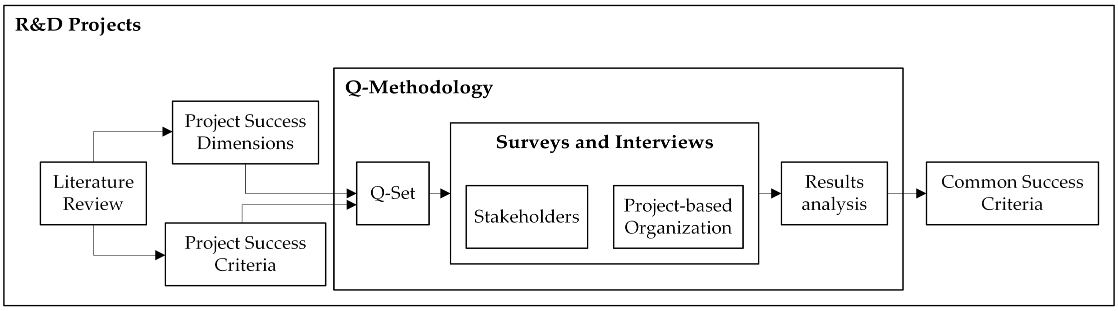

Fig. 2.7: Fifth Publication: "Project Success Criteria Evaluation for a Project-Based organisation and Its Stakeholders—A Q-Methodology Approach." - Research Methodology

With the data collected on Lean in Project-Based Organisations R&D, The DMAIC (Define, Measure, Analyse, Improve, Control) Methodology, Key Performance Indicators (KPIs), and Project Success, a model for identifying KPIs based on Lean principles were defined. Once the case study was defined, an analysis of the project data, the documentation related to the quality management of the research cluster, as well as the definition of the centre's strategic needs was carried out to have additional input for the establishment of the KPIs.
In the **Seventh Publication: "Hybrid project management methodology for R&D, Innovation and R&D&I projects in CFAA** (See Section 9.1) A literature review on topics related to the characteristics of R&D, innovation, and R&D&I projects, different approaches to project management for these types of projects, and a study on hybrid methodologies for project management were conducted in order to develop a hybrid methodology for the management of R&D, innovation, and R&D&I projects in a research cluster; and to be able to propose a hybrid management methodology for the innovation cluster. In semi-structured interviews, the cluster's PMs initially presented and accepted this methodology.
In the **Eighth Publication: "A data-driven approach for a new project management methodology based on quality increments.** (See Section 9.2), is stated in the Figure 2.8.

This publication analysed data from previous projects of a project-based organisation, looking for strengths and weaknesses in terms of results, methodology, information collected, and project success rate, among others. A review of the literature, analysing the role and uses that have been made of the use of quality as a measure of project performance, and on the other hand, analysing different hybrid methodologies for the management of R&D projects and how these can be a viable path for the correct management of these projects. Subsequently, and thanks to the data collected, a project management methodology based on quality increments is formulated, whose main objective is to facilitate project data collection. This methodology was tested in implementing activities for three projects with public-private funding.

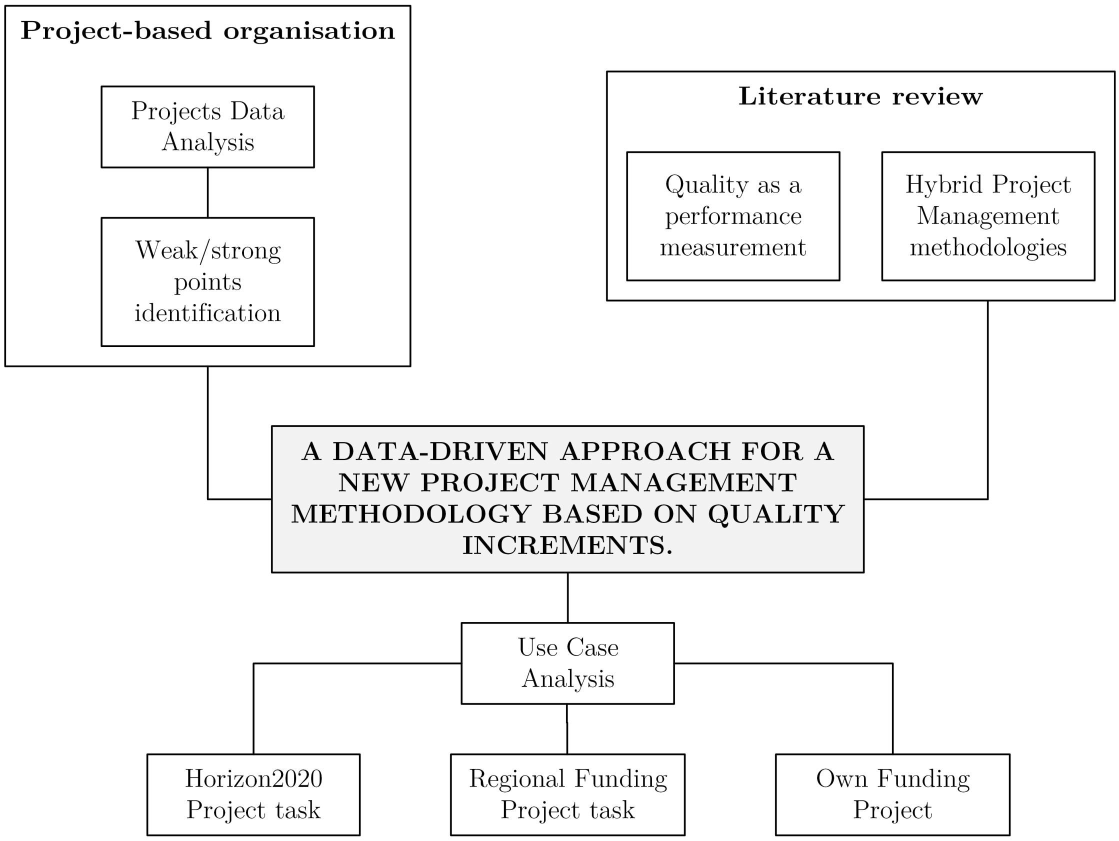

Fig. 2.8: Research Methodology JP4

3

Hypothesis and Objectives.

3.1 Hypothesis.

The main thesis hypothesis relies on the precept that quality is a measurable concept built progressively and incrementally throughout the project life cycle in an R&D project. The original concepts of the methodology are based on two foundations:

1. The work done by Paquin et al. [3] on the creation of Earned Quality Method (EQM) is founded on the idea that quality is a measurable concept and that quality is gradually built throughout a project's life cycle;

2. iterative and incremental development is a technique that combines the incremental construction model of agile methodologies with the iterative design method [4]. These two methodologies are complementary and are frequently utilised to increase efficiency and produce superior project deliverables.

The term Quality (which can be used with adjectives such as poor, good or excellent), according to the ISO 9000:2015 definition [2], is *the degree to which a set of inherent characteristics of an object meets requirements.*

As mentioned, the central hypothesis relies on the concept that the quality of a project is built progressively and incrementally and that with a correct definition of quality criteria between the organisation in charge of developing the project and its stakeholders and understanding the position of the TRL in which the project is developed, it is possible to i) measure the performance of the project, ii) evaluate the tasks carried out there, iii) achieve a better global result of the research, iv) allow the gradual evaluation of the results and v) the timely adjustments of the objectives and scope of the project; in addition to improving the collection of data from the project to be used in future research.

This hypothesis is motivated by the idea of improving the efficiency of resource use and the quality of results within the framework of an R&D project.

The novelty of this research lies in the following:

1. To use the principles described by Paquin et al. [3] and apply them in the context of an R&D project;

2. to propose a project management methodology in which quality is the central axis of the project and which allows the evaluation of the efficiency of the project, as well as timely decision-making, thus avoiding the misuse of resources;

3. to provide PMs with relevant information on the performance of tasks as input for future projects;

4. to provide new insights into what it means and how a successful R&D project is achieved.

3.2 Objectives.

The main and secondary objectives of the thesis are listed below.

3.2.1 General Objectives.

1. The first main objective of this thesis is to create a methodology based on Earned Quality Method (EQM) and data analysis to improve the efficiency of R&D projects in a near-real production environment in a TRL 5-7;

2. the second main objective of this thesis is to analyse and understand the role of the Technology Readiness Level (TRL) in which technology transfer projects are developed and to understand how it affects the regions in which some of these research centres are located;

3. the third main objective of this thesis is to define strategies for collaboration between public-private organisations through the study of related innovation centres whose aim is to promote the scientific, economic and social growth of their regions through collaboration with the public and private sectors;

4. the fourth main objective of this thesis is to analyse the role of project success within the metrics of an R&D project and what it means for stakeholders.

These main objectives are complemented through different types of scientific communications with the following secondary objectives:

3.2.2 Secondary Objectives.

1. To determine how an EQM approach can be used to obtain information on project performance in terms of quality;

2. to analyse how the correct management of TRLs can generate a transfer of technology and quality knowledge between the entities involved in the University-Industry Collaboration (UIC);

3. to analyse the characteristics of UIC and how the type of projects generated by these collaborations have special characteristics that require hybrid project management approaches to carry them out;

4. to measure and evaluate the progress of an R&D project through quality metrics, used as a measurable concept, established and agreed upon by the project development organisation and its stakeholders;

5. to identify the KPIs of project-based organisations and how these KPIs can influence the development of a project.

4

Summary and discussion of the results.

4.1 Summary and discussion.

In this section, we will summarise the conclusions and discuss the different contributions made during the development of the thesis, as seen in the Research Onion of the Thesis (Fig 4.1).

The structure of this section follows the indications published in the *Chapter XI. Thesis by published papers - Regulations Governing the Management of Doctoral Studies*[1]

[1] https://www.ehu.eus/en/web/doktoregoa/doctoral-thesis/thesis-by-published-papers - Last Access: 20/12/2022

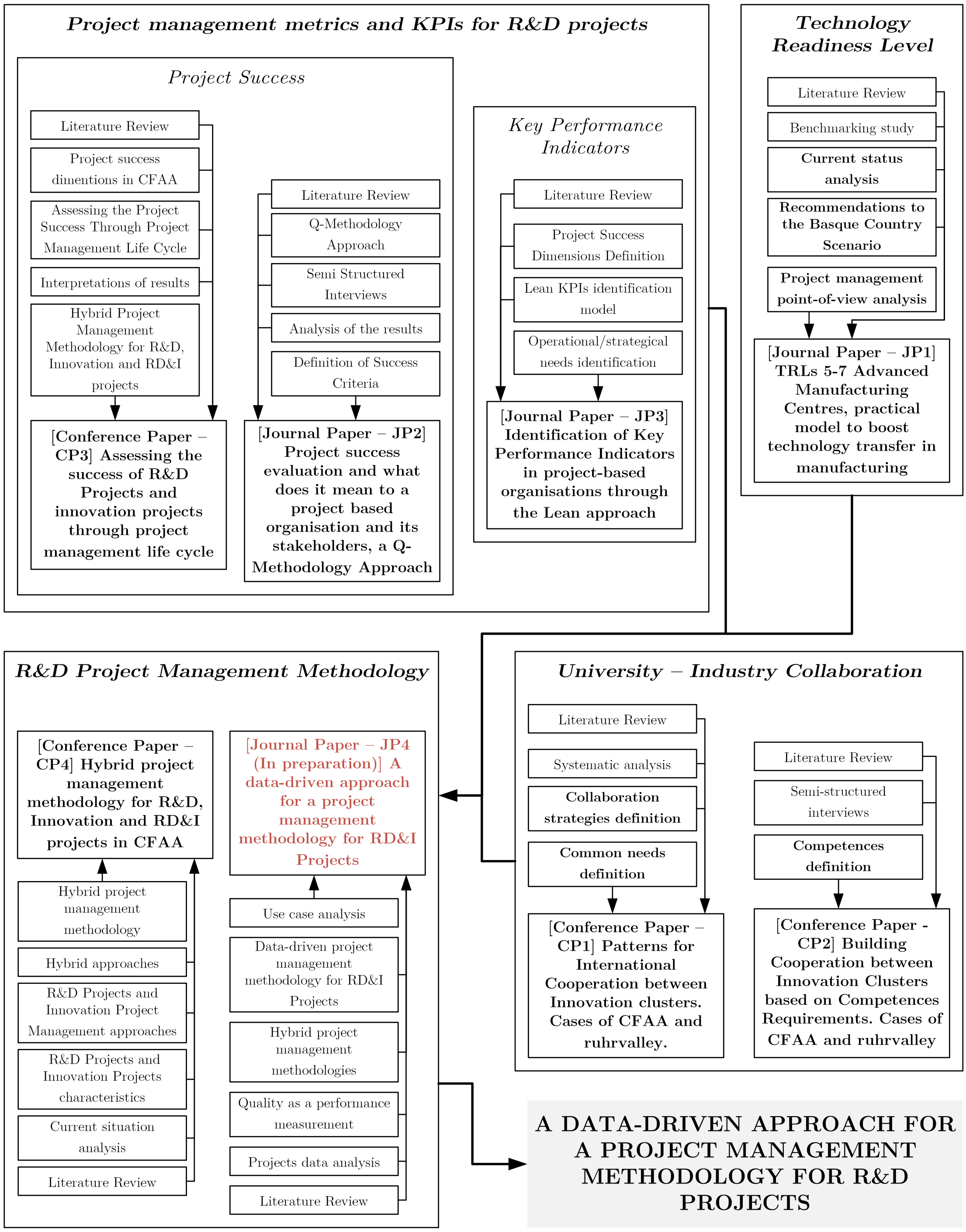

Fig. 4.1: Research Onion

4.1.1 First Publication CP.1 - Conference Paper: "Patterns for international cooperation between innovation clusters. Cases of CFAA and ruhrvalley".

The first publication (See Section 6.1) refers to the search for patterns for international cooperation between innovation clusters. This publication explores different possible means of collaboration between the CFAA and ruhrvalley (innovation cluster located in the Ruhr area, Germany [2]). Furthermore, it shows how with the knowledge and expertise gained from the projects, the clusters can improve their capabilities and help their partners through the rapid and better-applied use of knowledge with a new set of skills from this type of collaboration. It is also mentioned how international joint bidding can help improve the relationship between the expertise of both parties and help connect regions and their partners in innovation ecosystems.

This is consistent with what is stated in the academic literature (See Section 2.2.1) and the European Union [17] in terms of collaboration between R&D organisations. Apart from recommending a reinforcement of international scientific collaboration to increase scientific productivity and knowledge transfer, these collaborations are mentioned as one of the most important channels for disseminating and valuing knowledge. They also talk about how this type of collaboration generates better training for organisations' human capital, a more significant generation of patents and more excellent scientific production, among other aspects.

The publication also mentions the need for innovation clusters to gain competitive advantage, improve efficiency and show rapid, positive and valuable results can be achieved through such collaborative arrangements. We also refer to the many difficulties that need to be overcome, the lack of balance in terms of capacities to cope with valuable research, different institutional cultures, diversification of research activities, conflicts of interest, and risks generated from the publication of research results. However, it is also mentioned that these difficulties can be overcome with a concrete definition of objectives from the outset and with clear and understandable governance structures for the parties involved.

The main contribution of this publication is summarised in a description of the common needs of innovation clusters and the approach to support activities to meet these needs.

This publication is valuable for those innovation ecosystems that seek to establish relationships with similar clusters based on the Triple Helix model and that pursue the development of urban areas towards technology and innovation but with a focus on different industries.

This publication is aligned with the fulfilment of the Third Main Objective and First Secondary Objectives of the Thesis.

[2] https://ruhrvalley.tech/en/ - Last Access: 20/12/2022

4.1.2 Second Publication CP.2 - Conference Paper: "Building Cooperation between Innovation Clusters Based on Competences Requirements. Case of CFAA and ruhrvalley".

In this second publication (See Section 6.2), we address the issue of how to build cooperation between innovation clusters based on competence requirements.

As discussed in the first publication, an international collaboration between innovation clusters, as well as between public entities and industry, is sought and encouraged by the European Union. However, one of the requirements for such collaborations to work was based on a concrete definition of objectives and clear governmental structures. One of the components of this structure is the PM, which is why in this publication, we analyse what competencies are necessary for a PM and multi-skilled engineers to implement R&D projects successfully.

To achieve it, a broad set of competencies is needed. Some of these cannot be taught in traditional classrooms alone but instead require a learning environment with opportunities to gain practical experience. The study was conducted in these two innovation clusters because these locations offer such opportunities during the realisation of R&D projects.

In order to identify the sets of competencies required to collaborate and manage a research project and to find the skills that can be trained at the grassroots level in these clusters, interviews were conducted with different focus groups from the two clusters.

The main contribution of this publication is to provide a list of competencies required at technical, professional and global levels for R&D PMs. These competencies include problem-solving skills, knowledge and skills in scientific and systematic analysis, social skills, and critical and creative thinking.

The publication states that if there is a need to specifically describe prerequisites for working on a particular project, more interviews with project team members should be conducted, and assessment measures to evaluate required competencies should be developed.

We now understand that using artificial intelligence techniques for natural language processing might be beneficial for determining people's competencies based on the analysis of their CVs, publications, and project descriptions, among other [145].

This publication is aligned with the fulfilment of the Third Main Objective of the Thesis.

With these first two publications, we sought to analyse the main characteristics of innovation clusters, we looked for patterns to create collaboration strategies, and we analysed which sets of competencies PMs should have to participate in this type of collaboration.

We then moved on to the next step, which involved figuring out how to transfer the knowledge and findings from projects carried out within and among innovation clusters and the outcomes of cross-sector collaboration between the public and private sectors.

4.1.3 Third Publication JP.1 - Original Journal Paper: "TRLs 5–7 advanced manufacturing centres, practical model to boost technology transfer in manufacturing".

The third publication (See Section 7.1) is an original journal article which refers to a study carried out to create new advanced manufacturing centres whose activities focus on TRL 5 - 7. This publication sought to integrate small and medium-sized enterprises into the supply chain that can benefit from collaboration with universities and other research institutions by accessing shared and specialised knowledge.

Understanding this type of innovation cluster's characteristics, the publication looked at how to integrate more components into the aeronautical manufacturing value chain through a project management approach. The researchers applied it to the aeronautical sector in the Basque Country, identifying the necessary procedures needed for the success of these efforts and the knowledge domains that can make or break them.

We show throughout the publication that advanced manufacturing research centres can be a great solution to this problem in industrial sectors with structural knowledge and specialised skills deficits. We focus on the aerospace, machine tool and other supply chain sectors, as these sectors invest heavily in R&D. However, we were able to determine that most SMEs in the Basque Country need more fixed R&D structures to develop their research activities. Despite the significant efforts made by the public administration to improve universities and training centres and raise student qualifications, they collaborate with local companies to identify the significant failures of recent graduates.

One of the main conclusions of this study is to recommend that the ultimate goal of these research centres focused on advanced manufacturing should not be concentrated on horizontal developments of specific manufacturing technologies but should seek to engage in a wide range of manufacturing processes; integrating the development of process activities such as tool modelling, simulation, adaptive control of operation flow, automation, among others, reaching a level of maturity that allows the rapid and optimal flow of technology, avoiding risks in the technology portfolio of the partner companies. This way, industrial partners can undertake applied technological activities with a high probability of success.

The support of local, regional, national, and European governmental bodies is a crucial component of this ecosystem because sharing public and private funds can raise profit margins and partners' ability for R&D, which improves the likelihood of success for these kinds of projects.

This article has also been used as a starting point for examining the effects of the various factors impacting project management in facilities like these (the implementation of projects between public-private entities, the correct transfer of technology, funding and the different requirements for accessing and responding to these, as well as the quality of the research, carried out). Moreover, how this strategy can enhance project outcomes.

This publication is aligned with the fulfilment of the Second Main Objective and Second Secondary Objective of the Thesis.

The article mentions how the critical mass created through collaboration between companies, research centres, and universities promotes and improves the chances of obtaining funding for R&D activities, with participation in consortia in European or national projects under similar conditions with European reference centres, and with the possibility of choosing to participate in activities with a high rate of technological return, as well as access to broader funding.

We also talked about how, for small companies that participate in this type of research centres, it would mean an even more significant leap forward, bearing in mind their limitations in terms of R&D investment and the difficulty of constantly developing activities for the development or improvement of technologies.

We also emphasise integrating machine-tool manufacturers into the aeronautical manufacturing value chain. Participating in research projects with larger companies improves the chances of selling their products to the latter. In addition to gaining access to better financing schemes and improving proximity to the end customer, they also benefit from technological excellence inside and outside advanced manufacturing research centres.

Some other conclusions that can be drawn from the study are:

- Research centres around TRLs 5-7 should consist of several companies and universities and should be strongly supported by public administrations;
- supply chain collaboration with Original Equipment Manufacturers (OEMs) or Tier 1 is highly recommended, with the new hub model as a vertical conception;
- effort should be focused on one particular industrial sector;
- research centres of advanced manufacturing can boost the relative position of a university's research group with applied research to leading positions;
- the initial list of machines and systems is key to achieving intensive use of the centre's resources. Machines should be procured with a lifespan of at least seven years;
- the location in a technology park with common services is a key aspect of the project. The common services, the environment and easy access by public transport are key;
- with the idea that it should be a centre available to all partners and that management of the centre should genuinely be on behalf of the entire consortium. The centre should be managed by a university or technological agent.

We have already analysed, discussed and published various contributions regarding the functioning of public-private research centres and their place within regional and European business ecosystems, as well as the various characteristics needed to achieve a more efficient transfer of research results to end companies and to define patterns of collaboration between research centres and how this helps in obtaining better scientific results, as well as boosting local economies. Additionally, we were able to emphasise the significance of project management approaches that enable the quick transfer of high-quality knowledge and the relevance of a set of PM competencies for the participation and management of R&D projects in such centres.

The next step leads us to analyse these types of projects from the inside, both through the evaluation of success criteria and the assessment of this success by the research centre and its stakeholders, and the identification of KPIs for this type of organisation to improve the performance and results of the projects.

4.1.4 Fourth Publication CP.3 - Conference Paper: "Assessing the success of R&D projects and innovation projects through project management life cycle".

In this fourth publication (See Section 8.1), we enter the world of measuring the success of projects through research related to the evaluation of the success of R&D projects and innovation projects during their life cycle.

This publication is aligned with the fulfilment of the Fourth Main Objective of the thesis.

In this article, we discuss how the success of R&D projects impacts technological advancement and how difficult it is to manage and govern this kind of project. Focused on improving the management of R&D projects and avoiding dramatic failures, in this research, through a data-driven approach we investigated and determined several significant criteria for measuring the success of projects during the project life cycle.

The main contribution of this article is the identification of different dimensions and the evaluation, in order of importance for PMs, of success criteria for R&D projects carried out at the CFAA, as input to improve project management.

These criteria were validated and evaluated by conducting a survey of the PMs of the CFAA. These results revealed that the CFAA has been relatively successful in the execution of R&D projects and innovation projects and has the potential to improve the research pipeline and platforms for new technologies, innovation and creativity in the future. Furthermore, it is emphasised that the CFAA has been relatively successful in implementing projects on time and within budget, as well as in generating new knowledge and technological products.

During the evaluation of the success criteria and which were the most important for the managers, it was further concluded that since partner satisfaction was the factor that contributed least to the success of the project, customer-oriented strategies should be implemented to increase partner satisfaction, and thus improve the overall outcome of the projects.

This is mainly because the internal measurement of project success can and is, in fact, different from the stakeholder's perception of the projects. While some (the project developer) may consider a project finished on schedule and within budget to be successful, the research results may differ from what others demand (stakeholders). This is due to various factors, including the project's timing, the ease with which the results can be put into practice, the project's technological urgency, or even changes in the market. One of the subjects discussed in the following article is more research into the elements influencing stakeholders' perceptions of success.

4.1.5 Fifth Publication JP.2 - Original Journal Paper: "Project Success Criteria Evaluation for a Project-Based Organization and Its Stakeholders - A Q-Methodology Approach".

In this fifth publication (See Section 8.2), we refer to the measurement of project success evaluated from the point of view of stakeholders and PMs, who is in charge of developing the project, through the use of Q-Methodology.

In the publication, we emphasise that a project can no longer be seen solely as a temporary mission undertaken to create a single product, service or result. However, although the objective is the same, the elements surrounding the project have increased in both number and complexity. They must be viewed from a systems theory perspective [146], in which the system's inputs and components directly determine the system's outputs. Additionally, a system wherein the PMs are influenced by the behaviours or traditions that define an organisation may cause them to take actions that jeopardise the project's success as measured by the stakeholders. Understanding and schematising this complexity so it can be examined in detail to increase project success rates will be one of the most significant issues facing project management in the future.

One of the major concerns of organisations in terms of project management is to identify the project success criteria when evaluating or considering a project successful. With this idea in mind, the identification of a series of success criteria divided into different dimensions, defined from a literature review, and the subsequent discussion for their definition and the exercise developed using Q-Methodology gave us the possibility to create a list of these criteria for R&D projects and for that particular organisation.

One of the main contributions of this publication is to identify which are the most important success criteria in collaborative public-private R&D projects, according to the point of view of the organisation's PMs and internal stakeholders.

Based on the findings, the organisation's project managers, as well as the members of the Project Management Office, can now make plans, establish indicators and define methodologies and new checkpoints through which the success criteria identified in this study can be assessed. This evaluation can be carried out not only at the end of the project but also throughout its life cycle. [10].

Another point to note about the research conducted in this publication is the easy applicability to other types of organisations and projects. Thanks to the literature review, we have shown how important it is to know and consider the stakeholders' point of view in determining the success of projects and how this is not exclusive to R&D organisations carrying out collaborative projects but to any project organisation.

Another significant contribution of this publication is to identify the different subjective perspectives when assessing the success of projects from the point of view of stakeholders and PMs.

Q-Methodology offers the possibility to classify people into different groups that share the same subjective perspectives, called "Factors", thanks to which three factors were defined for the organisation:

- Factor 1: High quality-oriented to the output;
- factor 2: Traditional Project success oriented;
- factor 3: External view oriented.

For example, Factor 1, comprising about 50% of the participants, is characterised by getting the job completed correctly, which includes a focus on job site safety, following official standards for project deliverables to achieve greater customer satisfaction, both in the result and in the activities undertaken to achieve it. In addition to being characterised by a desire to meet customer expectations and enhance the organisation's reputation.

In general, the objective of identifying these factors is to clarify what these points of view are and who is included in them, as well as to be able to group the participants according to their points of view. Thanks to this, it is possible to focus efforts on meeting these expectations, implement practices aimed at managing these criteria, and improve project management from different points of view.

This publication is aligned with the fulfilment of the Fourth Main Objective of the Thesis.

Although a Q-Methodology exercise does not require a large number of participants, one of the critical limitations of this research was the sample size because the components did not indicate a strong tendency towards any of them. As already mentioned, these results can be used to improve the approach to R&D projects in the organisation and evaluate such projects' success.

Similarly, the identified criteria can redefine new KPIs for projects and the organisation or reevaluate existing metrics already utilised, depending on the context, for projects.

With the completion of these two publications, we were able to cover the topic of success measurement of R&D projects for organisations carrying out collaborative projects with public-private funding and looking for a fast technology transfer of the results. The conclusions of these publications facilitate the definition of quality criteria for projects which can be considered operational needs for the definition of Key Performance Indicators for project-based organisations.

4.1.6 Sixth Publication JP.3 - Original Journal Paper: "Identification of key performance indicators in project-based organisations through the lean approach".

In this sixth publication (See Section 8.3), we use lean principles and techniques to identify Key Performance Indicators in project-based organisations justified by their operational and organisational needs.

By applying lean thinking, organisations can learn more about themselves, ask questions that are sometimes skipped over, and come to important strategic decisions. In this research, through a Systematic Literature Review (SLR), the literature on identifying KPIs was analysed through a lean approach for project-based organisations.

Thanks to the concepts gathered, one of the main contributions of the publication was to identify a classification of KPIs and, from these, to develop a lean-based model to identify these KPIs., model that was applied to a case study conducted in a project-based R&D organisation. The model served as a guide for KPIs after a series of phases based on Lean tools and concepts. The steps of the DMAIC (Define - Measure - Analyse - Improve - Control) approach was used to maintain an organised process flow for developing the model.

The first action was to determine the organisation's actual state and investigate the Voice of the Customer (VoC) needs and requirements. To complement the initial information and determine the strategic needs (Voice of the Business (VoB)), the organisation's quality manual was reviewed, a requirement aligned with what is said in the scientific literature about the importance of formulating KPIs based on the organisation's strategic objectives as well as the corporate culture.

However, although this is a starting point towards the identification of performance indicators, the objective of this research should have included the analysis of corporate strategy and culture beyond the information that could be inferred from the organisation's quality manual and a data-driven analysis from projects carried out at the research Centre. On the other hand, and thanks to the experience gained from past publications, it was considered beneficial to benchmark with a similar organisation (ruhrvalley, innovation cluster located in the Ruhr area, Germany [3]), and thus create a baseline for the performance indicators. After obtaining the data and defining the CTQs, we proceeded to measure and analyse internal factors such as project success criteria and objectives and describe the performance indicators in the organisation.

The main contribution of this research is to define a set of qualitative and quantitative KPIs that assess the strategic and operational needs of a project-based organisation and help to understand and improve its performance criteria.

However, these KPIs cannot be set in stone. Instead, ongoing changes in the organisation, research methodology or the addition of new stakeholders need that KPIs to be

[3] https://ruhrvalley.tech/en/ - Last Access: 20/12/2022

regularly redefined and updated to ensure that the KPIs suit the present organisational context.

The objective of this research was limited to proposing a model for identifying KPIs using a lean approach; however, as a future line of research, it is suggested that actions to validate, communicate, report and control the adequacy of KPIs be continued. KPI dashboards are advised for use during the reporting, monitoring, and control of KPIs, in addition to the use of appropriate visual management approaches to manage the quality of KPIs, which are helpful for both the management of the organisation and the PMs.

This publication is aligned with the fulfilment of the Third Secondary Objective of the Thesis.

The findings of this study are precious to project-based organisations, particularly new ones that need help with properly designing a set of KPIs or whose direction is unclear.

With these identified KPIs, plus the definition of project success criteria, plus the understanding of TRLs and the analysis of collaboration in public-private organisations, the requirements for the formulation of a new methodology for project management in which quality is the central driver for measuring performance and improving the results obtained from the realisation of R&D projects were completed.

4.1.7 Seventh Publication CP.4 - Conference Paper: "Hybrid Project Management Methodology for R&D, Innovation and R&D&I Projects in CFAA".

The seventh publication (See Section 9.1) analysed a first model of a hybrid methodology for managing R&D, innovation and R&D&I projects in an organisation based on public-private funded projects seeking rapid technology transfer.

The proposed project management methodology has several characteristics that fit the R&D, innovation and R&D&I project environment. ***The vital contribution of this paper is that the proposed methodology's phases and stages ensure the capacity to govern and monitor projects, while iterations and spirals adopted from the agile approach allow for flexibility, learning, and responsiveness to flexible environments.*** In addition, iterations in the research phase are essential to reduce incremental scope changes and eventually reach the baseline scope of the project.

The second main contribution of the publication is that the proposed methodology paves the way to go back to the applied methods and practices to edit and modify them according to the feedback received from the main stakeholders. Furthermore, the Scrumban dashboard during the implementation phase is a useful communication tool for displaying the status of activities (to do, in progress, done), as well as blocked or rejected tasks, which reduces project efficiency.

Recommendations for meetings during the implementation phase are included, especially for problem-solving and acceleration of ongoing work. Last but not least, the storage and sharing of knowledge gained during the project offer the possibility to use this knowledge for similar projects in the future.

This methodology was presented and approved for use in the CFAA by the Centre's PMs. Despite the many advantages of its use, it was discovered that one of the primary requirements for project control and monitoring did not produce the desired results because the quality and previously specified success criteria of the project needed to be monitored appropriately. For this reason, although the methodology facilitated management and paved the way for the implementation of itinerant processes of evaluation and re-evaluation of the tasks within the stages, it did not achieve a well-founded implementation in the organisation.

This publication is aligned with the fulfilment of the First Main Objective of the Thesis.

For this reason, we studied how to implement the quality criteria, and KPIs identified for measuring project performance. With this information, we could propose a new methodology that considers these requirements.

4.1.8 Eighth Publication JP.4 - Original Journal Paper: "A data-driven approach for a new project management methodology based on quality increments".

The eighth publication (See Section 9.2) summarises the main findings of the thesis on a project management methodology. The methodology is designed to manage R&D projects using a data-driven approach and, through quality increments, to control the work carried out in research centres that carry out collaborative projects with public-private entities in high TRL.

Often, these projects are affected by a high uncertainty in their results due to the exploratory nature of the project. In addition, when conducted in SMEs, the management of results is often neglected [147]. However, ***The main contribution of this publication is that by analysing several projects, we found that through the use of the proposed methodology, the results of the projects met the stakeholder's requirements, academic results were obtained from the activities carried out and gave rise to new research.***

This publication is aligned with the fulfilment of the First and Fourth Main Objectives, and Forth and Fifth Secondary Objectives of the Thesis.

This article is in the last stages of preparation for submission to a scientific journal, so we will use this section to explain the primary outcomes of its use and its different characteristics.

The methodology has three main components:

1. An analysis of the current state of research centres like the CFAA from a project management point of view thanks to a benchmarking study carried out, a general analysis of the current state of the centres and some general recommendations for

the Basque Country scenario. All of this is with the intention of understanding and going deeper into the place within the production chain and the TRL of the place where the methodology is implemented. A research article has been published in this section [5];

2. for the methodology, it was necessary to analyse and study the role of university-industry collaboration as a complement to the previous point. Therefore, two research were developed, one to understand the patterns of international cooperation between innovation clusters [6] and another on how to create bridges for cooperation between these clusters [7]. In this way, it was possible to orientate towards the pursuit of goals through project management methodology and the best way to measure these collaborations in an R&D project environment. From this point, two conference research papers have been presented;
3. the third component is the definition of the objectives to be monitored for the success of an R&D project. Two approaches, Project Success and Key Performance Indicators were studied. The analysis of Project Success was carried out from two points of view, the first one ensuring the success of an R&D project through the analysis of the project management life cycle. Here, a hybrid project management methodology was proposed through the analysis of the success dimensions of the organisation, analysis and interpretation of information and scientific literature available at the time; the results were published in a paper published at a scientific conference [9]. The second component of Project Success was achieved by conducting a study using Q-Methodology and semi-structured interviews to define the success criteria of the projects carried out in the organisation from the point of view of the organisation and its stakeholders [10].
   Finally, concerning KPIs, research was carried out in which a lean approach was used to determine the key performance indicators for a project-based organisation. This information proved valuable in determining the KPIs for evaluating project performance. For this, a bottom-up approach was followed by determining which KPIs are fed by realising projects in the centre and, secondly, with these KPIs identified. Finally, they were grouped according to the quality criteria to evaluate the project.

The methodology was implemented and tested in three different projects. The first project with internal funding (UPV/EHU) in which a real-time machine monitoring platform was developed; the results have been presented in a research paper at an academic conference [12]. A second project with regional funding (Elkartek), in which the aim is to predict the wear of cutting tools in broaching operations. The results are being improved, and the development and conclusions will be presented in a research paper that is currently under preparation. Furthermore, the third was the development of a European-funded project task (Horizon 2020). The task aimed to develop virtual sensors for the manufacturing process of a machine through the analysis of available quality and process data. One article has been published with the development and conclusions of the machine assembly for data collection and analysis [13]. In addition, we are currently working on a second article in which the descriptions of the virtual sensors, the data analysis, and the conclusions obtained are presented.

This new methodology is aligned with the organisation's success criteria [8], determined by both stakeholders and PMs [10], the KPIs [11] (which allows it to be aligned with the organisation's strategy). The work to be carried out is understood at the TRL level where it is located [5, 6, 7]. It also helps with the strategic formulation of the project, which is validated through the correct and straightforward implementation of each of the proposed tools and activities.

The methodology is based on the premise that quality is a concept that can be measured and evaluated and progress achieved throughout the project life cycle. Furthermore, making use of the principles described by Paquin et al. [3], we rely on the fact that once the project objectives have been segmented, they can be evaluated according to their primary attributes and criteria, being easily related to the project activities. In this way, EQM allows PMs to periodically evaluate and control the quality gained from the final product.

A large amount of uncertainty about the achievement of the results is a point of comparison between a typical agile project and an R&D project; however, a point that differentiates them is that for an agile project, the product must be delivered in the shortest possible time, for an R&D project, the time to be consumed is understood to be longer than initially planned due to the explorative nature of the tasks. Even so, just because time is not a constraint in some cases does not mean that it should be treated as a secondary task and subject to the delivery of results; on the contrary, quality control of the tasks will help to determine if the objective can be met under the initially established terms, or if changes to these objectives are required.

The second distinction is related to one of the core values of an agile approach, *"working software over comprehensive documentation."* [148]. While the project's outcome is important for an agile approach, the outcome of an R&D project is just as important as the knowledge acquired during its development. Using information from task completion in an R&D project and an incremental approach towards goal fulfilment helps reduce uncertainty regarding future tasks' outcomes. Of course, the initial scheduling will be difficult for the first projects where the technology is unknown or no projects have been carried out in the technology line. However, proper classification, de-segregation and division of the task can serve as future input for new tasks scheduled for future projects.

External modifications brought to the project by stakeholders impact the completion of the initially planned objectives and tasks, but these occur less frequently in an R&D project. These modifications are more likely to occur towards the conclusion of a project from within it, when objectives, goals, and job scheduling are regularly re-evaluated and, at best, agreed upon with stakeholders. As a result, just as the agile approach to project management *"embraces changes during the project"* [148], similar modifications are also considered in an R&D project, although with different origins and various methods of obtaining consensus on the planned objectives.

4.1.8.1 New Methodology's phases and tools.

Taking as reference the study on Project success criteria evaluation for a project-based organisation and its stakeholders [10]; the study on Identification of key performance indicators in project-based organisations through the lean approach [11]; and the method proposed by Paquin et al., on Earned Quality Method [3]. In addition to the analysis and study of more than 300 R&D projects carried out at the CFAA [149], where the resources invested, the time spent, the results obtained, and the feedback from the partner were analysed; we have designed a project management methodology for R&D projects, based on the model proposed by Kerzner [150], as it provides a simple approach to the management of R&D projects.

In this methodology, the tools and approaches were developed and integrated according to the necessary step-by-step, from identifying the quality criteria required by the partner to realising the activities for their fulfilment and achievement of the project objective.

This section explains the proposed project management methodology designed to control and increase the quality of the work performed and the results obtained from internal and external projects of the organisation.

Due to the importance for the organisation and its stakeholders of meeting the partner's requirements in the performance of the activities during the project, the fulfilment of the project's objective and the generation of knowledge of the activities performed as well as the final result. The methodology includes different control points where, for example, the quality criteria proposed internally for the project must be approved and by those proposed by the project owner; In addition, steps are included in which the monitoring of the quality of the work performed must be analysed in order to avoid deviations from the project objective or a conscious and data-driven decision-making process, as well as different control points in which risk assurance is analysed, evaluated and controlled in order to minimise the probability of occurrence of risks and to achieve the project objective.

In the same way, given the importance for R&D organisations of achieving valuable results from the projects carried out, the proposed Quality Criteria Assessment helps to account for the work objectively carried out at the moments when it is decided, helps to improve objective and data-based decision making, as well as to reduce the likelihood of non-fulfilment of project objectives.

To manage the quality of the project, an extension of the method proposed by Paquin et al. [3] is proposed, in which the contribution of the activities set out in the Work Breakdown Structure (WBS) levels 3 and 4 is measured, in addition to proposing the generation of documentation aimed at improving the generation of knowledge for future projects, as well as the comparison of data generated by the project with projects carried out in the past; throughout the life cycle of the project.

The methodology can be used as well for organisations with no structured project management methodology or defined project management structures (due to limited resources available for structures such as this, as these must be directed towards the hiring of personnel, and the purchase of machines or software, processes defined in generic methodologies, such as PMBoK, are challenging to follow for small or medium-sized organisations)

The definition of quality criteria can only sometimes be extended to all organisations (for some organisations, the criteria set out here may be less critical or may vary drastically). Given the complexity involved, it is a simple exercise that should be carried out in organisations where projects are carried out with the collaboration of stakeholders. We proposed a method to overcome this issue (See [10]). In addition, the categorisation of KPIs helps to guide the efforts made in the projects and take advantage of the work done to improve the organisation's performance.

The organisation can arrange for quality assurance checkpoints to be done regularly based on the number of jobs to be completed, the estimated duration of the project, or the criticality of the tasks performed. In addition, partial project reports are proposed for this control to help reduce the frequency of project meetings.

The minimum acceptable quality for the work completed, as specified by the PMs and stakeholders, is one of the critical success factors for the proposed methodology and the project in general. The generation and application of corrective actions to improve quality performance or risk assurance are vital to correct the course of a project or to make decisions about the tasks performed, the personnel who perform them, the project's objective, and the tasks programmed, among others.

Task uncertainty implies low analyzability of R&D processes and makes it difficult to thoroughly plan and specify research tasks in advance [151]. As a result, there is a continuing need to collect and disseminate information to specify how to determine what is going on elsewhere and how to deal with disruptions [152].

Therefore, collaborative research projects with high task uncertainty imply that decisions must be made quickly. Consequently, a less centralised decision-making process is needed, as centralised communication patterns can cope with task-related uncertainty more effectively than hierarchical ones.

Increased task uncertainty in collaborative research leads to a greater decentralisation of coordination and control practices. Apart from task uncertainty, the balanced role of R&D personnel and R&D managers is also stimulated by the technology transfer objectives of the participants [55].

The fact that this methodology has been designed and based on the information and context of the CFAA does not mean that it cannot be applied outside the organisation or to projects that are not internal. Instead, the authors believe and rely on the scientific literature to state that a comprehensive yet simple and user-friendly PM's control of the quality of planned and executed activities is the primary input to maximise project results and achieve project objectives.

Following the recommendations of Ward & Chapman [153], the generic structure of a project should be described in four phases (a project conceptualisation phase, a second planning phase, a third phase outlining the execution of tasks, and finally, a project completion phase). However, the number of stages depends on the nature of the project (and the organisation's preparation) and might range from 4 to 8 or more [136].

According to Charvat [154], every proposed methodology should have project phases, which may vary depending on the size of the project, the organisation, or the industry, but certain typical phases should be included: concept, development, implementation, and support. According to these recommendations, the methodology proposed here is organised into four parts: definition, planning, execution and control, and evaluation and release. Based on the methodology proposed by Kerzner[150], Figure 4.2 describes the relationship between the project phases and the defined activities.

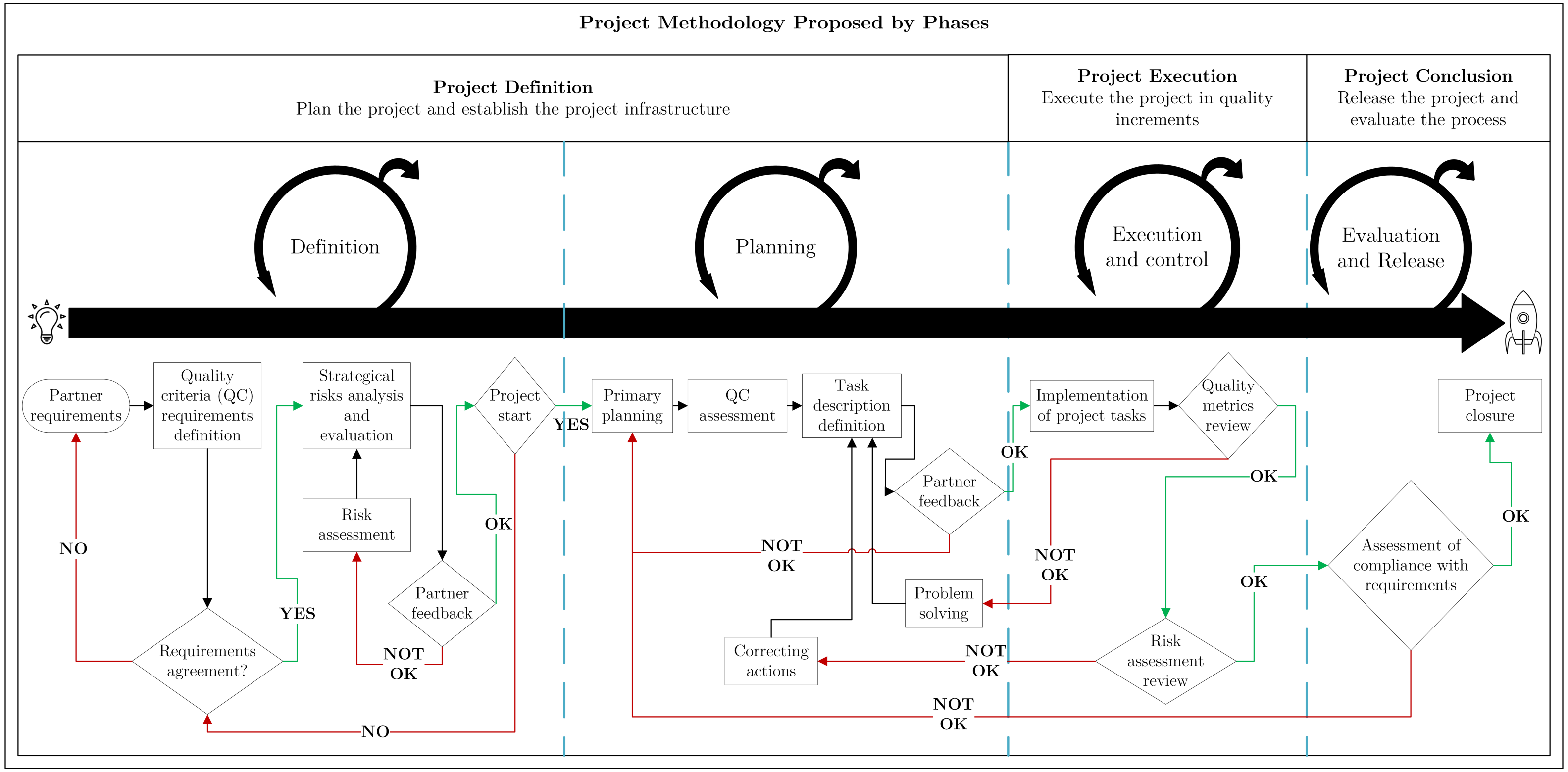

Fig. 4.2: Proposed Project Management Methodology in phases and activities

The documentation generated and at what point in the project, depending on the phase, is described in Figure 4.3.

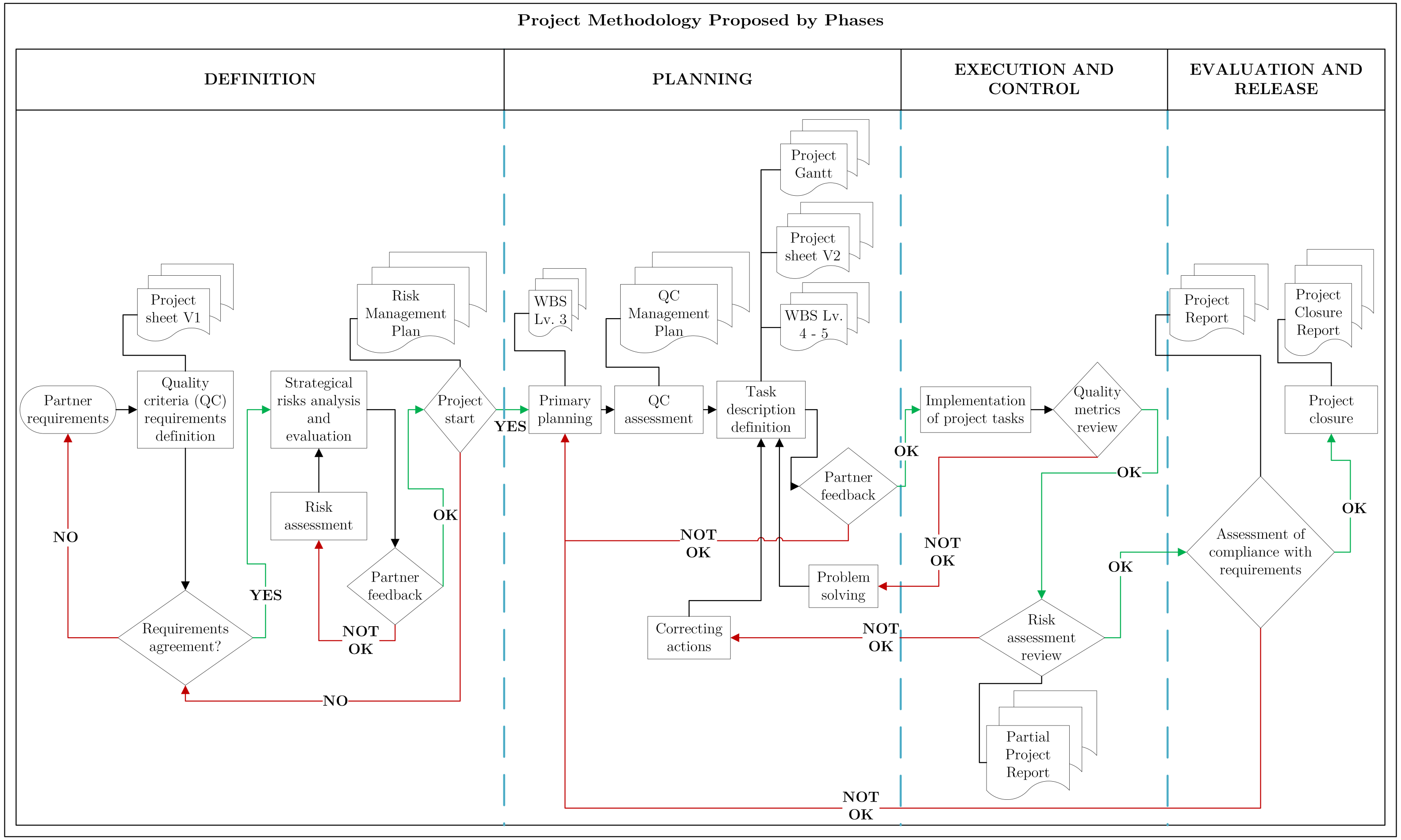

Fig. 4.3: Proposed Project management methodology including activities and documents

The documentation generated during the project is of vital importance in order to be able to create different databases with project information that will serve as inputs for future projects carried out by the organisation. In addition, we propose collecting information to create the databases described in Table 11.2.

We detail the phases and instruments that comprise the technique, as well as the primary objectives, actions, and outcomes for each step, following Chin's [155] suggestions.

4.1.8.2 Phases and tools description.

i Phase 1 - Project Definition.
The main objective of this phase is to generate the necessary information for project planning and establish the project's organisational infrastructure. The main objectives are:

- To define the partner's requirements for the project;
- to define, together with the partner, the quality criteria on which the project will be evaluated;
- to identify potential partners for the realisation of the project;
- to analyse, assess and document the potential risks of project development;
- to define the main objectives of the project;
- to develop the first version of the project sheet;
- to establish the collaboration agreement and the approval to start the project.

This **Phase 1** includes three activities and two decision steps:

i.i **Partner Requirements.**
The partner's requirements for realising a project are received in this first activity. These requirements must be aligned with the organisation's strategy and have the necessary physical and human resources to conduct the project.

i.i.i **External information:**

- **Scope requirements.**
  The scope of the project is defined, together with the main and secondary objectives of the project.
- **Technical requirements.**
  The technical requirements should be defined in as much detail as possible. It will be one of the criteria for evaluating the project's performance.
- **Quality Requirements.**
  The partner should provide an initial description of the quality requirements for the project.
- **Time requirements.**
  Similarly, an initial estimate of the time required to complete the project,

as required by the partner. Depending on the nature of the project, this may indicate how much time is available to complete the project.

i.i.ii **Internal information:**

- **Alignment with the strategy of the organisation.**
  Determine whether the project aligns with the organisation's research or business strategy.
- **Resources available, sufficient, and qualified.**
  The organisation should define whether it has the necessary resources to complete the project requirements.
- **Prioritisation of the project.**
  The project will be prioritised depending on the project type and the organisation's criteria. This decision can be made based on the objective and scope of the project.

i.ii **Quality Criteria (QC) requirements definition.**
The project objective, as well as the internal and external quality criteria for the project, must be defined in this activity, as well as the project managerial data (technology of the project, financing, type of project, partners involved, project code, prioritisation, Critical Success Factors (CSF) estimation; PM Assignment; Initial estimation of project hours (machines and staff, according to Partner's requirements; technology of the project and financing). The necessary information can be converted into a checklist for the organisation for its definition and further study. This information should be included in the first version of a project sheet. The quality criteria for evaluating the project should be at most ten items.

i.ii.i **External information:**

- **KPIs definition.**
  As far as possible, the partner shall define the KPIs that will govern the project based on the technical requirements, the organisation's success criteria and other available information.

i.ii.ii **Internal information:**

- **KPI List.**
  Based on the KPIs defined for the organisation, it is necessary to define which indicators are fed by the implementation of the project. In the same way, based on the nature of the project or the line of research to be followed, define which indicators can be fed by the implementation of the project.
- **Critical Success Factors.**
  Define which Critical Success Factors affect project delivery. If available,

select those CSFs defined by the organisation and jointly by the customer. [10].

- **Data Analysis about previous projects.**
  If data from previous projects are available, consult on similar projects that have been carried out, activities carried out, quality assessments, project results, and resources planned vs used, among others. An example of the databases generated using the proposed methodology is summarised in Table 11.2.

i.ii.iii **Documents:**

- **Project Sheet V1**.
  The first version of the project initiation document, with a summary of the agreements reached for the realisation of the project, will be generated. This sheet will include the project title, customers and contact details, financing, percentage of customer participation in the project, an initial estimation of machine hours and personnel, and start and estimated duration. In addition, a summary of the scope of the project, technical and quality requirements, and defined quality criteria.

i.iii **Requirements Definition.**
In this activity, the partner must be asked to approve the previously collected information and analyse the project's feasibility jointly. An agreement between the parties must be written down in Project Sheet V1.

i.iii.i **External information:**

- **Partner Feedback.** The partner must approve the information contained in Project Sheet V1. If not, the partner's requirements and the other information contained in Project Sheet V1 must be re-analysed.

i.iv **Strategical risks analysis and evaluation.**
In this activity, a strategic assessment of the project's risks must be conducted, including a description of the risks, the severity of occurrence, an assessment of the probability of occurrence, and the proposal of initial corrective and preventive actions for the occurrence of these risks.

i.iv.i **Internal information:**

- **Initial strategical risk evaluation (Description of risk; Severity and Likelihood evaluation, Corrective and Preventive Actions).**
  An initial study of the project risks, a description of the risks encountered, an assessment of the severity and probability of occurrence, and preventive and corrective action plans for the risks encountered must be carried

out.

i.v **Partner Feedback.**
With the information from the risk analysis, the partner will request feedback to check the feasibility of the project. In disagreement, a new project risk assessment must be carried out.

i.vi **Risk Assessment.**
If the partner disagrees with the risk assessment, this activity should be performed again, taking into account the comments received and the recommendations made by the partner for approval.

i.vii **Project Start.**
If a consensus has been reached for the realisation of the project in terms of technical requirements, time, quality, personnel and other components, the project will be formally initiated. A project initiation document (Project Sheet V1) will be generated and based on this, the contractual agreements for the realisation of the project will be generated.

i.vii.i **Documents:**

- **Risk Management Plan.**
  Suppose a consensus has been reached on the risk assessment and the proposed corrective and preventive actions. In that case, this information shall be recorded in a "Risk Management Plan" containing the definitive description of the risks, the severity and probability of occurrence, and the proposed corrective and preventive actions for their prevention. A person shall also be designated to monitor and control them. Once this has been done, the project can be formally launched.

ii **Phase 2 - Project Planning.** This is the main phase of the proposed methodology, as it covers project planning. The main objective of Phase 2 is to delve into the description of the activities and control requirements necessary to generate correct project planning. The information collected in Phase 1 will serve as input for this phase. The main objectives are:

- To carry out the description of the activities;
- to define and document, together with the partner, the quality criteria management plan on which the project will be evaluated;
- to plan the tasks and activities necessary to carry out the project;
- to generate the necessary information for project control;
- to develop the second version of the project sheet;

This **Phase 2** includes three activities and one decision step:

ii.i **Primary Planning.**
This activity, together with the required information on Phase 1, will result in the realisation of the WBS up to level 3. The first activities, the staff assignments and the scheduling (machine schedule) of the machines according to the prioritisation of the project will have to be planned. In addition, the project milestones must be defined according to the number and criticality of the tasks to be performed. The tasks must have information on the initial number of hours programmed, classification of the type of task (Table 11.2) and the person or group of people in charge of the task.

ii.i.i **Internal information:**

- **Staff assignation.**
  The people who will form the project team and carry out the activities will be defined.
- **Resource allocation.**
  If required, the resources needed to carry out the project tasks shall be described.
- **Operational risks analysis and evaluation.**
  This information will be added to the project's Risk Management Plan.
- **Milestones definition.**
  Project milestones will be defined in agreement with the partner.
- **Task Planning.**
  Initial planning of project tasks and activities will be carried out.

ii.i.ii **Documents:**

- **WBS Level 3.**
  At this point, levels 1 and 2 of the WBS should have been defined. With this information, plus the information collected in planning tasks and activities, level 3 of the WBS should be defined.

ii.ii **QC Assessment.**
Based on the information defined in the activity (i.ii), no more than ten quality criteria should be defined to assess the project. These criteria should group the quality criteria defined by the partner and the organisation's internal KPIs and Critical Success Criteria (CSC). Subsequently, and following the method described by Paquin et al. [3], the WBS -QBS will be created, which will have the information of which activities contribute to each of the defined quality criteria, as well as a valuation for that quality contribution (c_j). This information should be included in the **QC Management Plan**, together with the periodicity of

measurement of the criteria, the minimum quality margin to be achieved for the project, the steps to follow in case the quality objectives proposed for the project are not achieved, as well as the periodicity and frequency of the meetings for the follow-up of the project objectives. More information on how to carry out this step will be described in the practical example that was carried out for the project assessment (See Point 4.1.8.4.

ii.i **Internal information:**

- **KPIs definition on QC.**
  Based on the proposed KPIs, define the KPIs on which the project will be evaluated and which will feed each quality criterion defined for the project.
- **QC weighting.**
  Carry out the distribution of the weighting of the assessment of each quality criterion defined for the project in the tasks described up to WBS Level 2. The weighted sum of the weights of the WBS Level 2 assessments must be at most 1.
- **QC definition on tasks.**
  Based on each of the tasks described in WBS Level 3 and the weight of the assessment of each of the quality criteria in the WBS Level 2 tasks, a corresponding weight must be assigned to each of the WBS Level 3 tasks. The weighted sum of the weights of the WBS Level 3 assessments to which each of the WBS Level 2 activities corresponds must be at most 1.

ii.ii **Documents:**

- **QBS Level 3.**
  With the information collected, the Quality Breakdown Structure (QBS) should be generated up to level 3 (Figure 4.4).

ii.iii **Task description definition.**
In this activity, the tasks to be performed (WBS 4 - 5) are defined with greater specificity, and the description of the tasks, assignments, machine usage schedule and estimated time for the creation of the project Gantt should be included. The partners' project milestones, deliverables, and percentage participation shall be adjusted if necessary.

This information shall be included in the V2 of the project sheet. The different quality control tables, the outline of the potential contribution of the activities to quality, and the planned contribution of the scheduled work for each of the activities proposed in the WBS Lv 2, as well as the table of Planned quality of

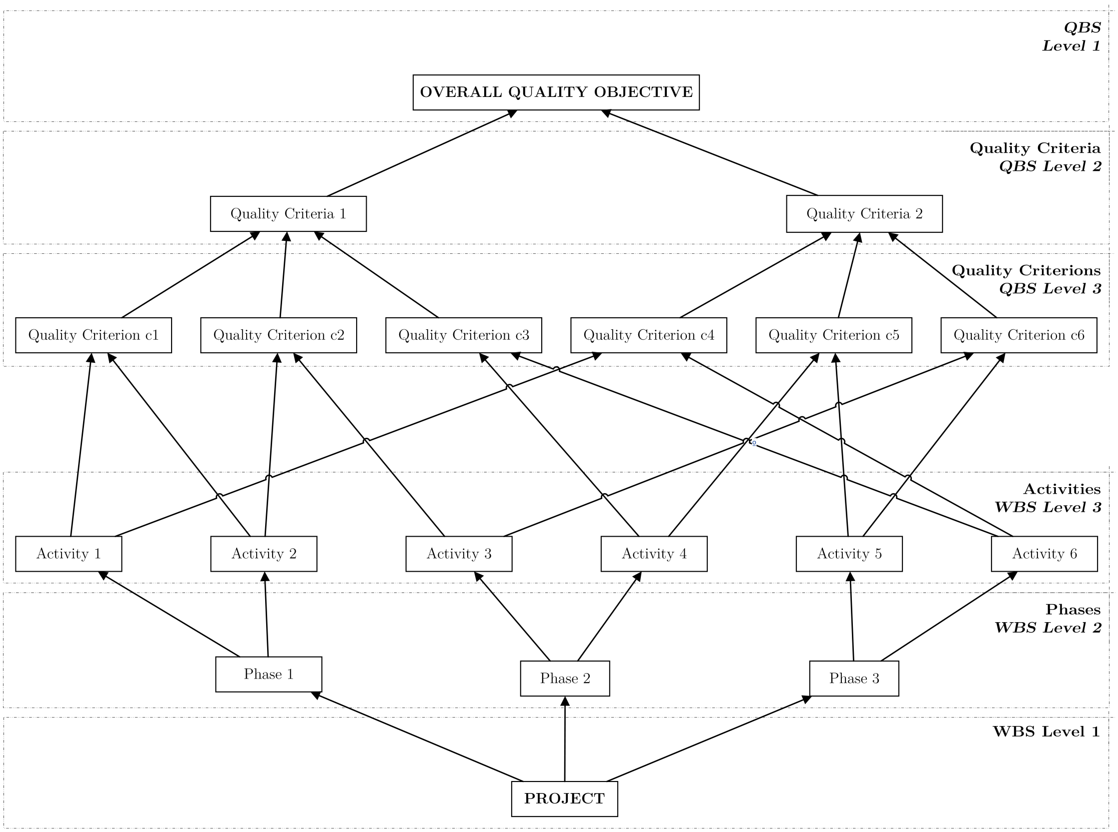

Fig. 4.4: QBS - WBS Example

the scheduled work (Table 4.19 from the practical example), will also be created.

ii.i **Internal information:**

- **Resource programming.**
  The scheduling of the machines will be carried out according to their availability and urgency.
- **Project Team Assignation.**
  Once the project team has been defined, the tasks to be carried out will be assigned to each of them.
- **Scheduling.**
  Based on the availability of the project team and machines, the scheduling of the tasks will be carried out.

ii.ii **Documents:**

- **WBS Level 4 – 5.**
  Where possible, the WBS document for Levels 4 and 5 will be generated with the available information.
- **Project Sheet V2.**
  In the new version of the project document, the quality criteria that will evaluate the project, the KPIs and Success factors that will feed those Quality Criteria, the QBS, and the WBS will be included.
- **Project Gantt.**
  With the available information on the definition of the tasks, the availability and reservation of the machines, and the availability of the people in the project team, the project Gantt will be created.

ii.iv **Partner Feedback.**
Once the requested information or the minimum necessary for the performance of the activities and the measurement in terms of quality is available, the partner must be asked for approval. In case of not approved, new planning of the WBS should be conducted and go back to **Primary Planning** to correct the observations or improvement points given by the partner.

iii **Phase 3 - Execution and control.**
Once the project planning has been completed and approved by the project partner, the project execution and development phase will begin. Phase 3 is a critical phase of the project, as the PM must constantly control and monitor the project's performance in terms of quality to ensure that it meets the stakeholders' expectations. The main objectives of this phase are:

- Ensure that project objectives are met as planned.
- Coordinate the implementation of activities according to the stipulated schedule and budget.
- Monitor requested changes based on the partial results obtained from the project and minimise their impact on the project scope, schedule and initial budget.
- Inform stakeholders about project performance through progress reports.

iii.i **implementation of project tasks.**
The required information for realising the tasks will be conveyed in a formal meeting with the project team. The implementation of the tasks will start.

iii.i.i **Internal information:**

- **Project Team Meeting.**
  Inform the project team about the details of the project, objectives to be achieved, quality criteria against which it will be evaluated, scheduling of tasks, and other available information.

iii.ii **Quality Metrics Review.**
Once the implementation of the project tasks has started, and whenever necessary according to the QC Management Plan, the review of the project quality metrics will also be initiated. For this, each of the activities described in Levels 4 and 5 shall be evaluated as they are carried out. In addition, the PM will evaluate the person(s) who carried out the activities on a scale of 0 to 1 according to the defined evaluation criteria). The information will be contained in the Actual Contribution of Work Performed on the tasks WBS Level 4 or 5 and WBS Level 2 according to the defined checkpoints.

iii.ii.i **Internal information:**

- **Technical evaluation of the tasks.**
  Evaluate the performance of the tasks in these terms, ensuring that the technical requirements set out at the beginning of the project are met.
- **QC Assessment.**
  Based on the defined quality criteria, evaluate the results of the tasks performed, keeping in mind the initial objectives planned for the project.
- **Project Team Meeting.**
  Schedule meetings according to the PM's criteria to inform the project team about the progress in completing the project tasks. Performance of the tasks based on the defined quality and technical criteria, reporting on possible changes that occur and managing these changes so that they affect the original project planning as little as possible.

iii.iii **Problem Solving Tasks.**
In case of deviations from the expected quality, the origin should be identified. Therefore, corrective actions should be taken to return the project to its ordinary and expected course. Otherwise, a redefinition of tasks (Activity ii.iii should be carried out to correct the course of the project.

iii.iv **Risk assessment review.**
In this activity, the risks defined and approved in Risk Management Plan (Activity i.vii.i) must be monitored. If new risks arise, the same process must be followed (description, severity assessment, probability and proposal of corrective and preventive actions). Whenever necessary, as established in the QC Management Plan, information on the time spent on each of the tasks, description of activities carried out; consolidation of research documentation; quality evaluation; Technical Evaluation; Lessons Learned; Meetings Report will be consolidated. This information will be delivered or made available in a Partial Project Report. This Partial Project Report can be delivered according to how the PM decided to work from the beginning.

iii.iv.i **Internal information:**

- **Risk evaluation.**
  Risks will be monitored as described in the Risk Management Plan (see Activity i.vii.i.

iii.iv.ii **Documents:**

- **Partial Project Report.**
  Based on the information collected, a partial project report will be made to the project partner. This report shall contain information on project performance in technical and quality terms, follow-up of identified risks, percentage of quality achieved up to that point and information on estimates for the fulfilment of project objectives and requirements.

iii.v **Correcting Actions.**
In case deviations from the risks or any identified risks have materialised, the necessary corrective or preventive actions will be taken.

iv **Phase 4 - Evaluation and release.** Phase 4 of the methodology includes measurement and evaluation of the project results, documentation of lessons learned, activities and so on, and official acceptance and delivery of the final product to stakeholders. In addition, the project partner will obtain an evaluation of the project. The main objectives of this phase are:

- Identify and measure project performance in terms of quality achieved.
- Document project-related information.
- Obtain acceptance of the completion of the project.
- Delivery of results and transfer of knowledge to stakeholders.
- Obtain external evaluation of the project's performance as input for future collaborations.

iv.i **assessment of compliance with requirements.**
Once the project activities have been carried out, evaluated and documented, the Quality Assessment Report, Technical Report; Milestones delivery; Results Report; Risk assessment report; Project representation delivery for partners and Meeting report will be carried out. The partner's feedback will be evaluated, and according to their criteria, the project activities will be finalised, or, on the contrary, the project will return to the Primary Planning (Activity ii.i) if necessary.

iv.i.i **External information:**

- **Partner feedback.**
  Based on the progress reports, the results obtained, the quality of the

project achieved, the project management, and others, the partner will be asked to evaluate the project in these terms.

iv.ii **Project Closure.**

For the closure of the project, the information contained in the Partial Project Reports and Project Sheets will be gathered; Lessons learned Documentation; Competence evaluation of Project Staff (in case there is a procedure for its realisation); Risk management documentation; a satisfaction survey of the project by the partner; all the information generated by the project (Project sheet, Meetings report, Trials and technical documentation; reports, presentations, and others.); and the QC Management Plan will be documented.

A meeting with the project team should be planned, and they should be asked for input on the project (scheduling of activities, the effectiveness of improvement efforts, identified improvement actions, and others.), as well as an overall assessment of the project conclusion. In addition, project team feedback (survey) and Project evaluation (survey) will be contained and archived in the Project Closure Report, which should be available for future study.

iv.ii.i **Internal information:**

- **Partial Project Reports.**
  All progress reports generated during the project should be collected and stored.
- **Project Sheet.**
  The Project Sheet with the information related to the project will be stored in databases duly organised for easy consultation.
- **Lessons Learned Documentation.**
  Based on the lessons learned throughout the project, documentation and database inclusion should be finalised and adequately organised for easy reference.
- **Competence evaluation.**
  The project manager should assess the development of the project team's competencies.
- **Risk Management Plan.**
  All information related to the Risk Management Plan should be stored for use and reference in future projects.
- **Project team feedback.**
  The project team will be asked for feedback on the project that was carried out, project management, problem solving and lessons learned during the project.
- **Partner Feedback.**
  The feedback received from the project partner will be included in the project documentation.

- **QC Management Plan.**
  The QC Management Plan shall be included in the project documentation and documentation relating to changes and developments during the project.
- **Project evaluation.**
  Finally, together with the project team and the PM, an evaluation of the realisation will be carried out, taking into account the achievement of the technical and quality objectives of the project, the project management, problem solving and lessons learned.

iv.ii.ii **Documents:**

- **Project Closure Report.**
  A project closure report will be created with the information collected during the project.

Another advantage of using this methodology is that comparing the quality gained with the planned quality of the work performed allows PMs to detect deviations in quality and initiate corrective actions early, avoiding the unnecessary expenditure of resources.

One of the main reasons why the methodology was defined in this way lies in the intention to obtain as much data as possible from the project, without this meaning more paperwork for the PM or the project team.

4.1.8.3 EQM description.

The EQM described by Paquin et al. [3]. was born as a proposal to allow the PMs to assess and control the quality of the final product throughout the project life cycle. We have discussed that the EQM is based on two fundamental premises. The first is that quality is a measurable concept, and the second is that quality accumulates progressively throughout the project's life cycle.

In their method, they start by elucidating the client's needs. To do this, the authors breaks down the overall quality objective into more detailed, lower-level objectives to clarify their meaning. This results in the Quality Breakdown Structure (QBS) that shows the hierarchy of the decomposition of the quality objectives. Partners' preferences are then evaluated and aggregated. In the original EQM assumed no interaction between the given attributes, making the value function additive.

Since the attributes and quality criteria are described in a hierarchical structure, the weights can be considered conditional evaluations. Thus the relative importance of the criterion c_j to the overall quality objective w_j is mathematically described by the Equation 4.1:

$$w_j = \sum_{k=1}^{K} a_k s_{jk} \quad for\ j = 1,\ \ldots,\ J \tag{4.1}$$

Where:

- J The number of criteria;
- K The number of attributes;
- v_k The attribute k of the QBS;
- a_k The relative contribution of attribute v_k to the overall quality objective

$$a_k \in [0,1] \, and \sum_{k=1}^{K} a_k = 1$$

- s_{jk} The relative contribution of criterion c_j to attribute v_k, $s_{jk} \in [0,1]$ and:

$$\sum_{j=1}^{J} S_{jk} = 1, \; for \; k \; = \; 1, \; ..., \; K$$

- w_j The relative contribution of criterion c_j to the overall quality objective, and:

$$\sum_{j=1}^{J} w_j = 1.$$

Assuming preferential independence between the tasks, the overall quality Q of the project's final product is equal to the weighted sum of the utility value of the results x_j obtained in all criteria J. Mathematically, we can write (Equation 4.2:

$$Q = \sum_{j=1}^{J} w_j \phi_j \left(x_j\right) \tag{4.2}$$

Estimating Earned Quality.
Once the QBS and WBS have been determined, the PM must define the criteria to which each activity contributes. The linkage between the WBS and the QBS allows the PM to establish a relationship between the activities and the quality attributes.
The PM then deepens the analysis by estimating the relative contribution of each activity to its related quality criteria. This can be done by attributing a conditional weight r_{ij} that measures the estimated relative contribution of activity a_i to criterion c_j.

The potential contribution of activity a_i's contribution q_i to the overall quality objective can be targeted as follows (Equation 4.3):

$$q_i = \sum_{j=1}^{J} w_j r_{ij} \; for \; i \; = \; 1, \; \ldots, \; I \tag{4.3}$$

Where:

- I The number of activities.

- r_{ij} The estimated contribution of activity a_i to criterion c_j, where, in addition:

$$r_{ij} \in [0,1]\,, and, \sum_{i=1}^{I} r_{ij} = 1, \quad for \;\; j = 1, \ldots, J.$$

Thus the contribution of each activity a_i to the overall quality can be decomposed into its contribution to criterion c_j and the contribution of criterion c_j to the overall quality.

Planned Quality of Work Scheduled $PQWS_t$

Planned work refers to the expected rate of completion of activities at time t, while earned work refers to the actual rate of completion of activities at time t. Planned quality refers to the expected quality that should have been accumulated at time t, while earned quality measures the actual quality accumulated at time t.

The planned quality of scheduled work $PQWS_t$ measures the planned contribution to the overall quality target attributable to scheduled work for all activities at time t. $PQWS_t$ is defined as follows (Equation 4.4)

$$\text{PQWS}_t = \sum_{i=1}^{I} \sum_{j=1}^{J} w_j \phi_j(x_j^*) r_{ij}^* (t) \tag{4.4}$$

Where:

- $r_{ij}^* (t)$ The expected contribution to the expected result x_j^*, as measured by criterion c_j, attributable to the work scheduled for activity a_i at time t, $0 \leq r_{ij}^*(t) \leq r_{ij}$

They assume that the scheduled work is such that its outcome will satisfy the customer's expectations x_j^* and, consequently, will lead to $\phi_j \left(x_j^* \right) = 1$. Thus, after completion of the project $PQWS_t = 1$.

Planned Quality of Work Performed $PQWP_t$

The Planned Quality of Work Performed $PQWP_t$ measures the planned contribution to the overall quality objective attributable to the work performed in all activities at time t. $PQWP_t$ is defined as follows (Equation 4.5:

$$\text{PQWP}_t = \sum_{i=1}^{I} \sum_{j=1}^{J} w_j \phi_j \left(x_j^* \right) r_{ij} (t) \tag{4.5}$$

Where:

- $r_{ij} (t)$ is the expected contribution to the expected result x_j^* measured by criterion c_j attributable to the work done in activity a_i at time t, $0 \leq r_{ij}(t) \leq r_{ij}$

Consequently, the project is completed at $PQWP_t = 1$

Earned Quality of Work Performed $EQWP_t$
The Earned Quality of Work Performed $EQWP_t$ measures the customer's overall satisfaction with the results obtained or the quality gained, attributable to the work performed on all activities at time t, Equation 4.6 gives the $EQWP_t$ at time t.

$$\text{EQWP}_t = \sum_{i=1}^{I} \sum_{j=1}^{J} w_j \phi_j \left(\hat{x}_j\right) \hat{r}_{ij} \left(t\right) \tag{4.6}$$

Where:

- $\hat{x}_j\left(t\right)$ The actual result obtained with respect to the criterion c_j of the work done at time t
- $\hat{r}_{ij}\left(t\right)$ The estimated contribution to the actual result $\hat{x}_j\left(t\right)$ according to criterion c_j attributable to the work done in activity a_i at time t.

Assessment of quality deviations and initiation of corrective measures.
Comparing the Earned Quality of Work Performed $EQWP_t$ with the Planned Quality of Work Performed $PQWP_t$ we obtain the quality variance (QV) at time t (Equation 4.7:

$$\text{QV}_t = \text{EQWP}_t - \text{PQWP}_t \tag{4.7}$$

The Quality Performance Index (QPI) at time t is calculated as follows (Equation 4.8):

$$\text{QPI}_t = \frac{\text{EQWP}_t}{\text{PQWP}_t} \times 100 \tag{4.8}$$

4.1.8.4 Practical examples of the use of the methodology.

The methodology has been tested in the realisation of three projects, as mentioned at the beginning of this section. (See Section 4.1.8):

i **Project1:** Project created for the development of a real-time machine monitoring platform.

ii **Project2:** Project created to predict the wear of cutting tools in broaching machining.

iii **Project3:** Project created for the development of virtual sensors for manufacturing processes through the analysis of machine data and part quality.

These projects were chosen for several reasons:

i **Sources of funding:**

- For **Project1**, the funding was internal, i.e. it came from the CFAA funds.
- For **Project2**, funds were used from a project submitted, approved by the Basque Government and financed by the "Elkartek" call, an instrument within the Basque Science, Technology and Innovation Plan (PCTI 2030), which aims to support collaborative research in strategic areas of fundamental and industrial research. [4]. Moreover, these are non-refundable grants.
- The **Project3** was developed within the framework of a European research project funded by the European Union under the EU research and innovation funding programme "Horizon 2020" [5], which was operational from 2014 to 2020, with a budget of around 80 billion euros.

ii **Project governance entities:**

- For **Project1**, the main governing entity of the project was the CFAA, which was the Research Centre where the project was carried out. A report justifying the work carried out, experimental and preliminary tests at the CFAA, and documentation related to the development of the project and the infrastructure, as well as publications either in conferences or in specialised scientific journals, are therefore requested.
- For **Project2**, the main governing entity of the project was the Basque Government, which has established minimum requirements for the acceptance of projects carried out with its funds [156].
  - "A performance report justifying the compliance with the conditions imposed in the award of the grant, indicating the activities carried out and the results obtained".
  - "Economic report justifying the cost of the activities carried out".
  - "Signed audit report drawn up by a person registered in the Official Register of Statutory Auditors under the Institute of Accounting and Auditing of Accounts."
  - "Expenditure Certification Document of the project, with the express Declaration of Concurrent Grants".

  Moreover, in this project, the UPV/EHU worked with seven other regional companies that formed the research consortium.
- For **Project3**, the main governing entity of the project was the EC, with the EC controlling and supervising the results of the projects and demanding minimum requirements for their acceptance from those who have been granted funding, among them:

[4] https://www.spri.eus/es/ayudas/elkartek/ - Last Access: 20/12/2022

[5] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020$_en - Last Access$: 20/12/2022

- Publication of research results in Open Access scientific journals and conferences.
- Open access to research data.
- A report justifying compliance with the technical and scientific conditions imposed in the award of the grant, indicating the activities carried out and the results obtained.
- Economic report justifying the cost of the activities carried out.
- Certification document of project expenditure, and others.

The UPV/EHU is part of a consortium of 25 European companies and research centres in this project. The work is focused on the coordination of two of the work packages and the implementation and participation in several of the activities of the other work packages.

iii **Technical and scientific requirements for projects:**

- For **Project1**, the technical and scientific requirements were formulated and agreed upon by the CFAA, the Project Manager and the Principal Investigator; and finally approved by the CFAA.
- For **Project2**, the technical and scientific requirements were formulated and agreed upon between the consortium's eight Research Centres and Universities members, aligned with the lines of research proposed by the Basque Government for the implementation of these projects. In this case, the Basque Government approved the technical and scientific proposals of the project under its criteria.
- For **Project3**, the technical and scientific requirements were formulated and agreed upon among the consortium's 25 member companies and research centres. These requirements were formulated according to the guidelines of the "Factories-of-the-Future (FoF) Public Private Partnership" call [6], EU research and innovation funding programme "Horizon 2020". In this case, the European Commission finally approved the required funding aligned to the technical and scientific proposals of the project.

A. ***Description of projects, project objectives and requirements - Activity i.i of the proposed Methodology (See section 4.1.8.2.)***

i **Project1 - Development of a real-time machine monitoring platform.**
For this project, the technical and quality requirements for project performance, objectives to be achieved, and time and costs were agreed upon between the CFAA and the project's lead researcher.

[6] https://www.effra.eu/factories-future - Last Access: 20/12/2022

i.i The project team consisted of four people:
- Lead researcher.
- Project manager.
- Project supervisor.
- Expert advisor.

i.ii The agreed objectives of the project were to:
- Create a digital twin on a CFAA machining centre.
- Perform an analysis of the variables (Programmable Logic Controller (PLC) and Computer Numerical Control (CNC)) necessary to monitor the machine in question.
- To achieve a scalable, high-performance implementation of the digital twin that enables near real-time data processing without loss of information.
- Create a monitoring dashboard that shows the data of the digital twin and the status of the variables being processed in streaming.
- Make use of 5G technologies for the virtualisation of services.

i.iii The technical requirements approved for the project were:
- Use open source technologies for data connectivity, processing, analysis and visualisation.
- Make use of industrial protocols for data ingestion.
- Development of a digital twin prototype using Spark Structured Streaming [7], running on a single node.
- The program must filter and process the defined variables.
- The deployed infrastructure shall be able to detect possible anomalies in the data through the detection of outliers.
- Use of database for the storage of data sorted through timestamps.
- Represent data through simple and intuitive graphs on a dashboard so CFAA members can understand what is happening on the machine.
- Remote operation of the infrastructure hosted on virtual machines in a private 5G network.
- Ensuring safe connection to the infrastructure.

i.iv The quality requirements for the project were:
- Detection of signal processing incidents and ensuring data persistence.
- Machine signal processing with high frequency.

[7] What is Apache Spark Structured Streaming? - https://docs.databricks.com/structured-streaming/index.html - Last Access: 20/12/2022

- Analysis of available open-source tools.
- Platform performance.
- Compliance with the initial schedule.
- Scientific publications generated from work done.

ii **Project2 - Prediction of cutting tool wear in broaching machining.**
For this project, the project's technical and performance quality requirements, objectives to be achieved, and times and costs were agreed upon between the consortium formed by the Research Centres and the Universities. The Basque Government subsequently approved these.
In this project, the work of the CFAA was reduced to carrying out one of the project tasks. The task was to use data analysis and the implementation of AI algorithms to predict the wear of cutting tools used in broaching machining. For this purpose, machine variables were used as features and wear as a target. Datasets from two machine tests that share similarities so that a single model is valid for both were used for the analysis. In addition, different machine learning models were examined to obtain the one that best fits the actual data.

ii.i The project team consisted of six people:
- Lead researcher.
- Task coordinator.
- Expert advisor.
- Three machine technicians researchers.

ii.ii The agreed objectives of the project were:
- Development of a behavioural model of manufacturing processes aimed at quality prediction (surface and geometric) for broaching.
- Development of functionalities for machine tool condition monitoring.
- Define and develop a data architecture that integrates information related to the manufacturing process and quality characterisation.

ii.iii The technical requirements approved for the project were:
- Determine relationships between process and part quality variables, allowing to establish process control actions at the machine level (real-time) and factory level (early defect detection).
- Creation of a monitoring system to characterise product quality.
- Cutting tool wear prediction.

ii.iv The quality requirements for the project were:
- Analysis of machine data on edge computing devices in real-time.

- Predict cutting tool wear with high accuracy.
- Compliance with the initial schedule.
- Model performance.
- Publications generated from work done.

iii **Project3 - Development of virtual sensors for manufacturing processes through analysis of machine data and part quality**.

For this project, the technical and quality requirements for project performance, objectives to be achieved, time and costs were agreed upon by the 25 European companies, research centres and universities forming the consortium. The European Commission subsequently approved these.

For this project, the UPV/EHU was responsible for managing two work packages and participating in several tasks in six of the nine work packages. We will show the information related to completing one of these tasks. Specifically, this task consisted of developing virtual sensors (a virtual sensor is a *"pure software sensor which autonomously produces signals by combining and aggregating signals that it receives (synchronously or asynchronously) from physical, or other virtual sensors"* [157]), for process control, which was able to determine the state and the different phenomena (breaks, wear, and others.) occurring in the cutting tool, based on the real-time analysis of the machine data and the data obtained from the surface quality of the part. Different artificial vision techniques were used to isolate, measure, and identify breaks and wear on the cutting tools to determine the surface quality of the part.

iii.i The project team consisted of nine people:

- Four researchers.
- Task coordinator.
- Expert advisor.
- Three machine technicians researchers.

iii.ii The agreed objectives of the project were:

- Development of a virtual sensor for the broaching process.
- Define and develop a data architecture that integrates information related to the manufacturing process and quality characterisation.

iii.iii The technical requirements approved for the project were:

- Determine relationships between process and tool quality variables.
- To determine by creating a virtual sensor the different phenomena occurring in the cutting tool during the broaching process.
- Cutting tool wear prediction.

iii.iv The quality requirements for the project were:

- Analysis of available machine and sensor data.
- Wear data analysis.
- Correlations between machine and wear data.
- Compliance with the initial schedule.
- Model performance.
- Publications generated from work done.

iv Definition of Quality Criteria Requirements for projects.

Based on the information gathered from the review of KPIs (Table 11.1) and the CSC (Table 11.3) from CFAA, the quality requirements defined for each of the projects were analysed to determine which of those mentioned above were affected by the quality requirements defined for each of the projects.

This information can be found in Table 4.1.

ID	**Category**	**Description**	**Project 1**	**Project 2**	**Project 3**
CSC - 1	CSC - Cost Management	Return on Investment of the project	X	X	X
CSC - 2	CSC - Knowledge Management	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)	X	X	X
CSC - 3	CSC - Quality Management	Customer satisfaction regarding the deliverable.	X	X	X
CSC - 4		Customer satisfaction regarding the quality of delivery activities of the specific project	X	X	X
CSC - 5		Degree to which the deliverable meets its intended purpose.	X	X	X
CSC - 6		The deliverable meet the defined quality criteria.	X	X	X
CSC - 7	CSC - Risk Management	Workplace Safety	X	X	X
CSC - 8	CSC - Scope Management	Project goal was achieved	X	X	X
CSC - 9	CSC - Stakeholder Management	Delivery activities have a good reputation	X	X	X
CSC - 10		Reputation of the organization has increased	X	X	X
KPI - 1	KPI - Financial	Increase the return of investment of the projects	X	X	X

KPI - 2	KPI - Life-Cycle	Detect, analyse and resolve non conformities at time	X	X	X
KPI - 3		Keep the technical capacities needed for the project's development.	X	X	X
KPI - 4	KPI - Operational	Assure by any possible means that the project's results are useful for the project partner	X	X	X
KPI - 5		Generate new usable knowledge and engineering solutions	X	X	X
KPI - 6		Increasing awareness of CFAA as a centre of excellence	X	X	X
KPI - 7		Involve personnel from partner companies as active actors in the implementation and development of projects		X	X
KPI - 8		Mobilisation of resources for projects as needed	X	X	X
KPI - 9		Project development according to the partners' expectations	X	X	X
KPI - 10	KPI - Project	Increase the reputation of PMO	X	X	X
KPI - 11		Performance monitoring and evaluation of projects development and results	X	X	X
KPI - 12		Risk evaluation of realised opportunities (known unknowns) and suffered threats	X	X	X

KPI - 13	KPI - Strategic	Contribute to the advancement of knowledge and social development through RD and innovation	X	X	X
KPI - 14		Contribute to the creation of wealth in the Basque Country, supporting and promoting sustainable competitiveness of Basque Country Companies		X	
KPI - 15		Develop a competitive and strong RDI network in Biscay		X	
KPI - 16		Develop, test, establish and transfer theory and methodology.	X	X	X
KPI - 17		Encourage the participation of students in the development of projects	X		
KPI - 18		Expand existing cooperation into strategic innovation partnerships		X	X
KPI - 19		Find partners eager to share and collaborate with knowledge, commercial and technical interests.		X	X
KPI - 20		Increase demand orientation in transfer		x	X
KPI - 21		Involve local companies of strategical sectors in RDI projects		X	
KPI - 22		Participation in programmes initiatives of the EU Research Framework Programme			X
KPI - 23		Strategic potential of the projects developed	X	X	X
KPI - 24	KPI - Sustainability	Assure fluid communication with the partner before, during and after the development of the project	X	X	X
KPI - 25		Contribute to sustainability in the creation, design and result of deliverables from the projects	X	X	X
KPI - 26		Issuing central reference publications	X	X	X
KPI - 27		Increase publication output and conference attendances	X	X	X

KPI - 28	KPI - Technical	Assure fluid communication with the partner before, during and after the development of the project	X	X	X
KPI - 29		Enable and encourage talent early on	X	X	
KPI - 30		Ensure the financial, scientific and international success of the CFAA and the continuity of the activities		X	X
KPI - 31		Implement trouble-shooting methods and process	X	X	X
KPI - 32		Increase publication output and conference attendances	X	X	X
KPI - 33		Issuing central reference publications	X	X	X
KPI - 34		Meet the technical and management objectives of the Centre	X		
KPI - 35		Scientific publications from project results in refereed journals	X	X	X

Table 4.1: CSC and KPIs chosen per project

Having analysed the quality requirements for each of the projects and knowing which are the KPIs and CSCs whose performance depends on these requirements, a rating (c_j) is then given to each of the project's quality requirements. For Project 1, the following assessment was decided upon (Table 4.2):

c_j	**Id**	**Quality Criteria Requirements**	**CSC & KPIs**
0.15	P1QC1	Analysis of available open-source tools.	KPI - 17, KPI - 28, KPI - 29, KPI - 31, KPI - 34.
0.05	P1QC2	Compliance with the initial schedule.	CSC - 4, CSC - 7, KPI - 2, KPI - 3, KPI - 10, KPI - 11, KPI - 12, KPI - 31.
0.15	P1QC3	Detection of signal processing incidents and ensuring data persistence.	KPI - 17, KPI - 28, KPI - 29, KPI - 31.
0.15	P1QC4	Machine signal processing with high frequency.	KPI - 17, KPI - 28, KPI - 29, KPI - 31.
0.2	P1QC5	Platform performance.	CSC - 1, CSC - 3, CSC - 5, CSC - 6, CSC - 8, KPI - 1, KPI - 4, KPI - 5, KPI - 6, KPI - 8, KPI - 9, KPI - 14, KPI - 31.
0.3	P1QC6	Scientific publications generated from work done.	CSC - 2, CSC - 9, CSC - 10, KPI - 13, KPI - 14, KPI - 16, KPI - 23, KPI - 24, KPI - 25, KPI - 27, KPI - 26, KPI - 32, KPI - 33, KPI - 35.

Table 4.2: Quality Criteria definition - Project 1

For Project 2, the following assessment was made (Table 4.3):

c_j	**Id**	**Quality Criteria Requirements**	**CSC & KPIs**
0.2	P2QC1	real-time analysis of machine data on edge computing devices.	KPI - 7, KPI - 21, KPI - 28, KPI - 29, KPI - 31.
0.1	P2QC2	Compliance with the initial schedule.	CSC - 4, CSC - 7, KPI - 2, KPI - 3, KPI - 10, KPI - 11, KPI - 12, KPI - 19, KPI - 30, KPI - 31.
0.2	P2QC3	Model performance.	CSC - 1, CSC - 3, CSC - 5, CSC - 6, CSC - 8, KPI - 1, KPI - 4, KPI - 5, KPI - 6, KPI - 8, KPI - 9, KPI - 14, KPI - 31.
0.2	P2QC4	Predict cutting tool wear with high accuracy.	KPI - 7, KPI - 21, KPI - 28, KPI - 29, KPI - 31.
0.3	P2QC5	Publications generated from work done.	CSC - 2, CSC - 9, CSC - 10, KPI - 13, KPI - 14, KPI - 15, KPI - 16, KPI - 18, KPI - 20, KPI - 23, KPI - 24, KPI - 25, KPI - 27, KPI - 26, KPI - 32, KPI - 33, KPI - 35.

Table 4.3: Quality Criteria definition - Project 2

For Project 3, the following assessment was made (Table 4.4):

c_j	**Id**	**Quality Criteria Requirements**	**CSC & KPIs**
0.15	P3QC1	Analysis of the available machine and sensor data.	KPI - 7, KPI - 11, KPI - 31.
0.05	P3QC2	Compliance with the initial schedule.	CSC - 4, CSC - 7, KPI - 2, KPI - 3, KPI - 10, KPI - 11, KPI - 12, KPI - 19, KPI - 30, KPI - 31.
0.15	P3QC3	Correlations between machine and wear data.	KPI - 7, KPI - 11, KPI - 31.
0.2	P3QC4	Model performance.	CSC - 1, CSC - 3, CSC - 5, CSC - 6, CSC - 8, KPI - 4, KPI - 5, KPI - 6, KPI - 8, KPI - 9, KPI - 31.
0.3	P3QC5	Publications generated from work done.	CSC - 2, CSC - 9, CSC - 10, KPI - 13, KPI - 16, KPI - 18, KPI - 20, KPI - 22, KPI - 23, KPI - 24, KPI - 25, KPI - 27, KPI - 26, KPI - 35.
0.15	P3QC6	Wear data analysis.	KPI - 7, KPI - 11, KPI - 31.

Table 4.4: Quality Criteria definition - Project 3

After partner feedback (Activity i.v), the implementation of the risk analysis and assessment strategy (Activity i.iv), and the final approval by the partners for each of the projects, each of the projects was formally launched (Activity i.vii).

In this section, we will show the development of Project 3.

v Quality Assessment
As described in Activity ii.ii, the WBS - QBS is created (Figure 4.5) and to define, based on the QBS - WBS, the allocation scheme for the potential contribution of activities to quality (Table 4.5).

c_j / Activity a_i	r_{ij}						Allocation scheme
	P3QC1	P3QC2	P3QC3	P3QC4	P3QC5	P3QC6	
	0.150	0.050	0.150	0.200	0.300	0.150	
P3Ph1 - Management and planning		1.000					0, 20%, 40%, 60%, 80%, 100%
P3Ph2 - Data analysis activities	0.700			0.150	0.200	0.200	0, 25%, 50%, 75%, 100%
P3Ph3 - Wear analysis activities				0.150	0.200	0.500	0, 25%, 50%, 75%, 100%
P3Ph4 - Correlation and modelling			0.500	0.500	0.200	0.200	0, 50%, 100%
P3Ph5 - Evaluation and release	0.300		0.500	0.200	0.200	0.100	0, 25%, 50%, 75%, 100%
P3Ph6 - Post-project evaluation					0.200		0, 100%

Table 4.5: Allocation scheme of the potential contribution of the activities to quality

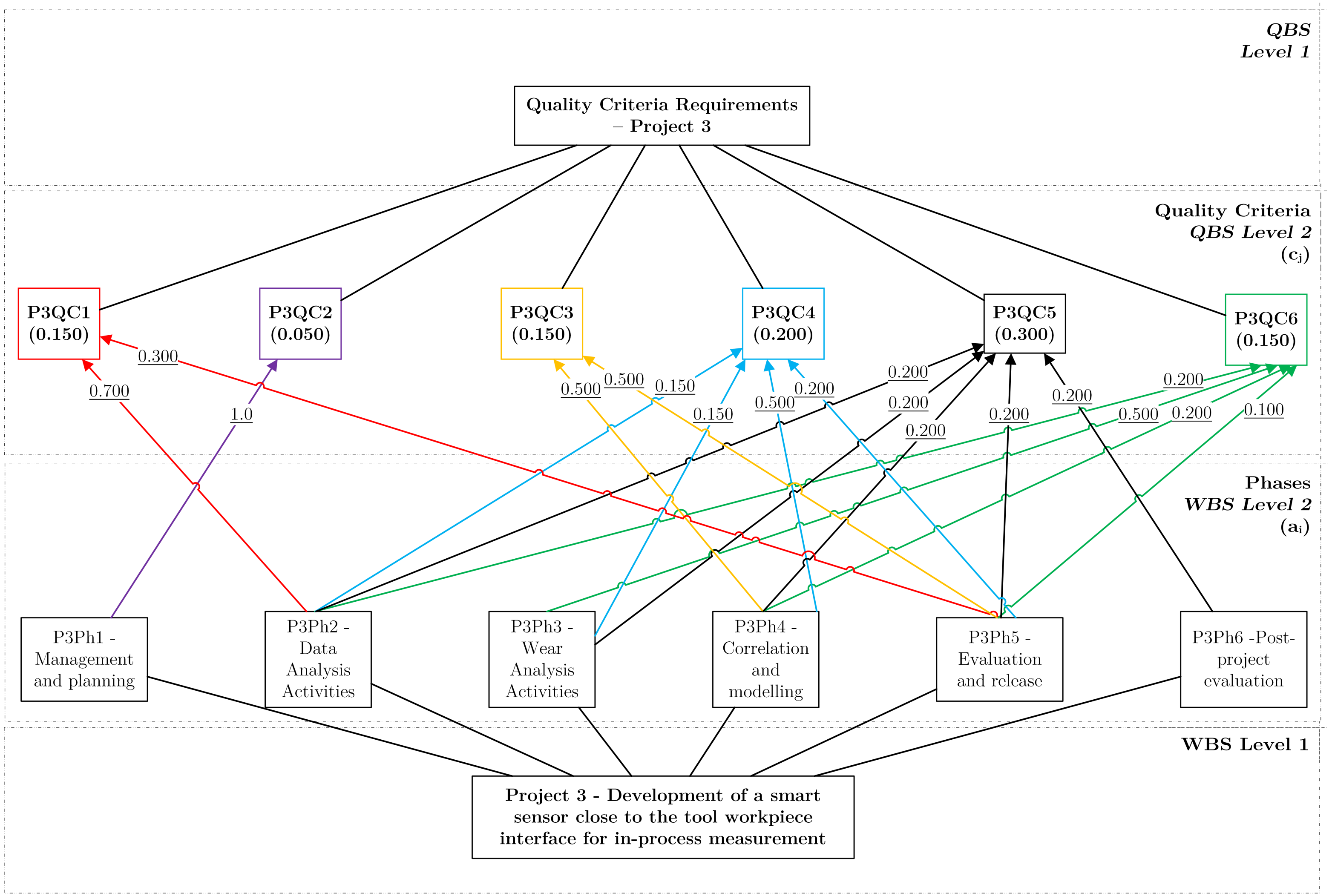

Fig. 4.5: QBS - WBS Project 3

vi Task Description definition.
Following the methodology, the tasks to be carried out in the project are defined. The contributions of each of the subtasks r_{ij} of the activities a_i to each of the criteria c_j to be assessed for the project, at level 3 and 4 of the WBS and QBS, are described:

- Phase 1: "Management and planning."

WBS Level 2	**P3Ph1 - Management and Planning**			
WBS Level 3	**P3Ph1 - 1.1**	**P3Ph1 - 1.2**	**P3Ph1 - 1.3**	**P3Ph1 - 1.4**
c_j	**0.250**	**0.250**	**0.250**	**0.250**
Task WBS Level 4	r_{ij}			
P3Ph1 - 1.1.1	0.167			
P3Ph1 - 1.1.2	0.167			
P3Ph1 - 1.1.3	0.167			
P3Ph1 - 1.1.4	0.167	0.111		
P3Ph1 - 1.1.5	0.167			
P3Ph1 - 1.1.6	0.167	0.111		
P3Ph1 - 1.2.1		0.111		
P3Ph1 - 1.2.2		0.111	0.250	
P3Ph1 - 1.2.3		0.111		
P3Ph1 - 1.2.4		0.111		
P3Ph1 - 1.2.5		0.111		
P3Ph1 - 1.2.6		0.111		
P3Ph1 - 1.2.7		0.111		
P3Ph1 - 1.3.1			0.250	
P3Ph1 - 1.3.2			0.250	
P3Ph1 - 1.3.3			0.250	
P3Ph1 - 1.4.1				1.000

Table 4.6: Phase 1: QBS-WBS levels 2, 3 and 4.

- Phase 2: "Data analysis activities."

WBS Level 2	**P3Ph2 - Data Analysis Activities**	
WBS Level 3	**P3Ph2 - 2.1**	**P3Ph2 - 2.2**
c_j	**0.500**	**0.500**
Task WBS Level 4	r_{ij}	
P3Ph2 - 2.1.1	0.167	
P3Ph2 - 2.1.2	0.167	
P3Ph2 - 2.1.3	0.167	
P3Ph2 - 2.1.4	0.167	
P3Ph2 - 2.1.5	0.167	
P3Ph2 - 2.1.6	0.167	
P3Ph2 - 2.2.1		0.333
P3Ph2 - 2.2.2		0.333
P3Ph2 - 2.2.3		0.333

Table 4.7: Phase 2: QBS-WBS levels 2, 3 and 4.

- Phase 3: "Wear analysis activities."

WBS Level 2	**P3Ph3 - Wear Analysis Activities**	
WBS Level 3	**P3Ph3 - 3.1**	**P3Ph3 - 3.2**
c_j	**0.500**	**0.500**
Task WBS Level 4	r_{ij}	
P3Ph3 - 3.1.1	0.143	
P3Ph3 - 3.1.2	0.143	
P3Ph3 - 3.1.3	0.143	
P3Ph3 - 3.1.4	0.143	
P3Ph3 - 3.1.5	0.143	
P3Ph3 - 3.1.6	0.143	
P3Ph3 - 3.1.7	0.143	
P3Ph3 - 3.2.1		0.200
P3Ph3 - 3.2.2		0.200
P3Ph3 - 3.2.3		0.200
P3Ph3 - 3.2.4		0.200
P3Ph3 - 3.2.5		0.200

Table 4.8: Phase 3: QBS-WBS levels 2, 3 and 4.

- Phase 4: "Correlation and modelling."

WBS Level 2	**P3Ph4 - Correlation and modelling**	
WBS Level 3	**P3Ph4 - 4.1**	**P3Ph4 - 4.2**
c_j	**0.500**	**0.500**
Task WBS Level 4	r_{ij}	
P3Ph4 - 4.1.1	0.333	
P3Ph4 - 4.1.2	0.333	
P3Ph4 - 4.1.3	0.333	
P3Ph4 - 4.2.1		0.500
P3Ph4 - 4.2.2		0.500

Table 4.9: Phase 4: QBS-WBS levels 2, 3 and 4.

- Phase 5: "Evaluation and release."

WBS Level 2	**P3Ph5 - Evaluation and release**			
WBS Level 3	**P3Ph5 - 5.1**	**P3Ph5 - 5.2**	**P3Ph5 - 5.3**	**P3Ph5 - 5.4**
c_j	**0.250**	**0.250**	**0.250**	**0.250**
Task WBS Level 4	r_{ij}			
P3Ph5 - 5.1.1	1.000			
P3Ph5 - 5.2.1		1.000		
P3Ph5 - 5.3.1			0.250	
P3Ph5 - 5.3.2			0.250	
P3Ph5 - 5.3.3			0.250	
P3Ph5 - 5.3.4			0.250	
P3Ph5 - 5.4.1				0.500
P3Ph5 - 5.4.2				0.500

Table 4.10: Phase 5: QBS-WBS levels 2, 3 and 4.

- Phase 6: "Post-project evaluation."

WBS Level 2	**P3Ph6 - Post project evaluation**				
WBS Level 3	**P3Ph6 - 6.1**	**P3Ph6 - 6.2**	**P3Ph6 - 6.3**	**P3Ph6 - 6.4**	**P3Ph6 - 6.5**
c_j	**0.200**	**0.200**	**0.200**	**0.200**	**0.200**
Task WBS Level 4	r_{ij}				
P3Ph6 - 6.1.1	1.000				
P3Ph6 - 6.2.1		1.000			
P3Ph6 - 6.3.1			1.000		
P3Ph6 - 6.4.1				1.000	
P3Ph6 - 6.5.1					1.000

Table 4.11: Phase 6: QBS-WBS levels 2, 3 and 4.

Gantt Chart of the project.
With the information collected, we defined the Gantt chart of Project 3 and the control points (cp) for the project.

Time (days)	15	30	45	60	75	90	105	120	135	150	165	180	195	210
P3Ph1 Management and planning	cp	cp	cp	cp	cp	cp								
P3Ph2 Data analysis					cp	cp	cp	cp						
P3Ph3 Wear analysis							cp	cp	cp	cp				
P3Ph4 Correlation and modelling									cp	cp				
P3Ph5 Evaluation and release									cp	cp	cp	cp		
P3Ph6 Post-project evaluation													cp	cp

Table 4.12: Gantt Chart of the project

With the information collected from the control points, plus the inputs from each of the sub-tasks of the activities, the tables for the Planned Contribution of Work Scheduled (PCWS) (See section 4.1.8.3) can be created:

PCWS: P3Ph1 - Management and planning.

t	P3QC2 (0,050) $r_{11} = 1{,}0$ $r_{11}^{cp}(t)$	Weighted sum $\sum_j w_j \phi_j \left(x_j^{cp}\right) r_{1j}^{cp}(t)$
15	0,167	0,008
30	0,333	0,017
45	0,500	0,025
60	0,667	0,033
75	0,833	0,042
90	1,000	0,050

Table 4.13: PCWS: P3Ph1

PCWS: P3Ph2 Data analysis activities.

t	P3QC1 (0,150) $r_{22} = 0{,}700$ $r_{22}^{cp}(t)$	P3QC6 (0,150) $r_{23} = 0,200$ $r_{23}^{cp}(t)$	P3QC4 (0,200) $r_{25} = 0{,}150$ $r_{25}^{cp}(t)$	P3QC5 (0,300) $r_{26} = 0{,}200$ $r_{26}^{cp}(t)$	Weighted sum $\sum_j w_j \phi_j \left(x_j^{cp}\right) r_{1j}^{cp}(t)$
75	0,175	0,050	0,038	0,050	0,056
90	0,350	0,100	0,075	0,100	0,113
105	0,525	0,150	0,113	0,150	0,169
120	0,700	0,200	0,150	0,200	0,225

Table 4.14: PCWS: P3Ph2

PCWS: P3Ph3 - Wear analysis activities.

t	P3QC6 (0,150) $r_{33} = 0{,}500$ $r_{33}^{cp}(t)$	P3QC4 (0,200) $r_{35} = 0{,}150$ $r_{35}^{cp}(t)$	P3QC5 (0,300) $r_{36} = 0{,}200$ $r_{36}^{cp}(t)$	Weighted sum $\sum_j w_j \phi_j \left(x_j^{cp}\right) r_{1j}^{cp}(t)$
105	0,125	0,038	0,050	0,041
120	0,250	0,075	0,100	0,083
135	0,375	0,113	0,150	0,124
150	0,500	0,150	0,200	0,165

Table 4.15: PCWS: P3Ph3

PCWS: P3Ph4 - Correlation and modelling.

t	P3QC6 (0,150) $r_{43}=0{,}200$ $r^{cp}_{43}(t)$	P3QC3 (0,150) $r_{44}=0{,}500$ $r^{cp}_{44}(t)$	P3QC4 (0,200) $r_{45}=0{,}500$ $r^{cp}_{45}(t)$	P3QC5 (0,300) $r_{46}=0{,}200$ $r^{cp}_{46}(t)$	Weighted sum $\sum_j w_j\phi_j\left(x^{cp}_j\right)r^{cp}_{1j}(t)$
135	0,100	0,250	0,250	0,100	0,133
150	0,200	0,500	0,500	0,200	0,265

Table 4.16: PCWS: P3Ph4

PCWS: P3Ph5 - Evaluation and release.

t	P3QC1 (0,150) $r_{52}=0{,}300$ $r^{cp}_{52}(t)$	P3QC6 (0,150) $r_{53}=0{,}100$ $r^{cp}_{53}(t)$	P3QC3 (0,150) $r_{54}=0{,}500$ $r^{cp}_{54}(t)$	P3QC4 (0,200) $r_{55}=0{,}200$ $r^{cp}_{55}(t)$	P3QC5 (0,300) $r_{56}=0{,}200$ $r^{cp}_{56}(t)$	Weighted sum $\sum_j w_j\phi_j\left(x^{cp}_j\right)r^{cp}_{1j}(t)$
135	0,075	0,025	0,125	0,050	0,050	0,059
150	0,150	0,050	0,250	0,100	0,100	0,118
165	0,225	0,075	0,375	0,150	0,150	0,176
180	0,300	0,100	0,500	0,200	0,200	0,235

Table 4.17: PCWS: P3Ph5

PCWS: P3Ph6 - Post-project evaluation.

t	P3QC5 (0,300) $r_{66}=0{,}200$ $r^{cp}_{66}(t)$	Weighted sum $\sum_j w_j\phi_j\left(x^{cp}_j\right)r^{cp}_{1j}(t)$
195	0,100	0,030
210	0,200	0,060

Table 4.18: PCWS: P3Ph6

In the same way, we can define the table of the Planned Quality of the Work Scheduled (PQWS) (See Section 4.1.8.3).

Activity, a_i	15	30	45	60	75	90	105	120	135	150	165	180	195	210
P3Ph1	0,008	0,017	0,025	0,033	0,042	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
P3Ph2	-	-	-	-	0,056	0,113	0,169	0,225	0,225	0,225	0,225	0,225	0,225	0,225
P3Ph3	-	-	-	-	-	-	0,041	0,083	0,124	0,165	0,165	0,165	0,165	0,165
P3Ph4	-	-	-	-	-	-	-	-	0,133	0,265	0,265	0,265	0,265	0,265
P3Ph5	-	-	-	-	-	-	-	-	0,059	0,118	0,176	0,235	0,235	0,235
P3Ph6	-	-	-	-	-	-	-	-	-	-	-	-	0,03	0,06
$PQWS_t$	0,008	0,017	0,025	0,033	0,098	0,163	0,26	0,358	0,59	0,823	0,881	0,94	0,97	1

Table 4.19: Planned quality of work scheduled

Now, assuming that the project starts and finishes within the planned time, it can be said that the Planned Contribution of the Work Performed (PCWP) would be:

Activity, a_i	15	30	45	60	75	90	105	120	135	150	165	180	195	210
P3Ph1	0,008	0,017	0,025	0,033	0,042	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,050	0,05
P3Ph2	-	-	-	-	0,056	0,113	0,169	0,225	0,225	0,225	0,225	0,225	0,225	0,225
P3Ph3	-	-	-	-	-	-	0,041	0,083	0,124	0,165	0,165	0,165	0,165	0,165
P3Ph4	-	-	-	-	-	-	-	-	0,133	0,265	0,265	0,265	0,265	0,265
P3Ph5	-	-	-	-	-	-	-	-	0,059	0,118	0,176	0,235	0,235	0,235
P3Ph6	-	-	-	-	-	-	-	-	-	-	-	-	0,03	0,06
$PQWP_t$	0,008	0,017	0,025	0,033	0,098	0,163	0,26	0,358	0,59	0,823	0,881	0,94	0,97	1

Table 4.20: Planned contribution of the work performed

vii Quality Metrics Review (See section iii.ii)

For Project 3, 3 control points were defined to review the project quality metrics. The activities were carried out within the scheduled time, and there were no deviations from the plan. Therefore, we will show the evaluation of each project task in the Actual Contribution of Work Performed (ACWP) tables (See section 4.1.8.3).

The evaluation was carried out from 0 to 1, with 1 being the optimal result of the task in terms of quality.

The following ratings were obtained for the first phase of the project:

t	c_j	$P3Ph1.1$ 0,25	ϕ_j	$P3Ph1.2$ 0,25	ϕ_j	$P3Ph1.3$ 0,25	ϕ_j	$P3Ph1.4$ 0,25	ϕ_j	Weighted sum
15	P3Ph1 - 1.1.1	0,167	0,9	-	-	-	-	-	-	0,038
	P3Ph1 - 1.1.2	0,167	0,8	-	-	-	-	-	-	0,033
	P3Ph1 - 1.1.3	0,167	0,8	-	-	-	-	-	-	0,033
30	P3Ph1 - 1.1.4	0,167	0,9	0,111	0,7	-	-	-	-	0,057
	P3Ph1 - 1.1.5	0,167	1	-	-	-	-	-	-	0,042
45	P3Ph1 - 1.1.6	0,167	0,9	0,111	1	-	-	-	-	0,065
	P3Ph1 - 1.2.1	-	-	0,111	0,8	-	-	-	-	0,022
	IQT2.2 - 1.2.2	-	-	0,111	1	0,25	0,5	-	-	0,059
60	IQT2.2 - 1.2.3	-	-	0,111	0,8	-	-	-	-	0,022
	P3Ph1 - 1.2.4	-	-	0,111	0,9	-	-	-	-	0,025
	P3Ph1 - 1.2.5	-	-	0,111	0,8	-	-	-	-	0,022
	P3Ph1 - 1.2.6	-	-	0,111	1	-	-	-	-	0,028
75	IQT2.2 - 1.2.7	-	-	0,111	0,9	-	-	-	-	0,025
	P3Ph1 - 1.3.1	-	-	-	-	0,25	1	-	-	0,063
90	IQT2.2 - 1.3.2	-	-	-	-	0,25	1	-	-	0,063
	IQT2.2 - 1.3.3	-	-	-	-	0,25	0,8	-	-	0,050
	P3Ph1 - 1.4.1	-	-	-	-	-	-	1	0,9	0,225

Table 4.21: Actual contribution of work performed - Phase 1

The information collected in Table 4.21, can be summarised as follows:

t	P3QC2 (0,050) $r_{11} = 1{,}0$		Weighted sum $\sum_j w_j \phi_j(\hat{x}_j)\hat{r}_{1j}(t)$
	$r_{11}^{cp}(t)$	$\phi_1(\hat{x}_1)$	
15	0,167	0,1042	0,001
30	0,333	0,2028	0,003
45	0,5	0,3493	0,009
60	0,667	0,4465	0,015
75	0,833	0,534	0,022
90	1	0,8715	0,044

Table 4.22: ACWP - P3Ph1

Following the same evaluation method, assessments were made of the activities carried out in the subsequent phases of the project.

Actual contribution of work performed - P3Ph2

t	P3QC1 (0,150) $r_{22} = 0{,}700$		P3QC6 (0,150) $r_{23} = 0{,}200$		P3QC4 (0,200) $r_{25} = 0{,}150$		P3QC5 (0,300) $r_{26} = 0{,}200$		Weighted sum $\sum_j w_j \phi_j(\hat{x}_j)\hat{r}_{2j}(t)$
	$r_{22}^{cp}(t)$	$\phi_2(\hat{x}_2)$	$r_{23}^{cp}(t)$	$\phi_3(\hat{x}_3)$	$r_{25}^{cp}(t)$	$\phi_5(\hat{x}_5)$	$r_{26}^{cp}(t)$	$\phi_6(\hat{x}_6)$	
75	0,175	0,225	0,050	0,225	0,038	0,225	0,050	0,225	0,013
90	0,350	0,442	0,100	0,442	0,075	0,442	0,100	0,442	0,050
105	0,525	0,742	0,150	0,742	0,113	0,742	0,150	0,742	0,125
120	0,700	0,892	0,200	0,892	0,150	0,892	0,200	0,892	0,201

Table 4.23: ACWP - P3Ph2

Actual contribution of work performed - P3Ph3

t	P3QC6 (0,150) $r_{33} = 0{,}500$		P3QC4 (0,200) $r_{35} = 0{,}150$		P3QC5 (0,300) $r_{36} = 0{,}200$		Weighted sum $\sum_j w_j \phi_j(\hat{x}_j)\hat{r}_{3j}(t)$
	$r_{33}^{cp}(t)$	$\phi_3(\hat{x}_3)$	$r_{35}^{cp}(t)$	$\phi_5(\hat{x}_5)$	$r_{36}^{cp}(t)$	$\phi_6(\hat{x}_6)$	
105	0,125	0,136	0,038	0,136	0,050	0,136	0,006
120	0,250	0,314	0,075	0,314	0,100	0,314	0,026
135	0,375	0,633	0,113	0,633	0,150	0,633	0,078
150	0,500	0,893	0,150	0,893	0,200	0,893	0,147

Table 4.24: ACWP - P3Ph3

Actual contribution of work performed - P3Ph4

t	P3QC6 (0,150) $r_{43} = 0{,}200$		P3QC3 (0,150) $r_{44} = 0{,}500$		P3QC4 (0,200) $r_{45} = 0{,}500$		P3QC5 (0,300) $r_{46} = 0{,}200$		Weighted sum $\sum_j w_j \phi_j (\hat{x}_j) \hat{r}_{\mathbf{4}j} (t)$
	$r_{43}^{cp} (t)$	$\phi_3 (\hat{x}_3)$	$r_{44}^{cp} (t)$	$\phi_4 (\hat{x}_4)$	$r_{45}^{cp} (t)$	$\phi_5 (\hat{x}_5)$	$r_{46}^{cp} (t)$	$\phi_6 (\hat{x}_6)$	
135	0,100	0,467	0,250	0,467	0,250	0,467	0,100	0,467	0,062
150	0,200	0,917	0,500	0,917	0,500	0,917	0,200	0,917	0,243

Table 4.25: ACWP - P3Ph4

Actual contribution of work performed - P3Ph5

t	P3QC1 (0,150) $r_{52} = 0{,}300$		P3QC6 (0,150) $r_{53} = 0{,}100$		P3QC3 (0,150) $r_{54} = 0{,}500$		P3QC4 (0,200) $r_{55} = 0{,}200$		P3QC5 (0,300) $r_{56} = 0{,}200$		Weighted sum $\sum_j w_j \phi_j(\hat{x}_j) \hat{r}_{5j}($ t)
	$r_{52}^{cp}(t)$	$\phi_2(\hat{x}_2)$	$r_{53}^{cp}(t)$	$\phi_3(\hat{x}_3)$	$r_{54}^{cp}(t)$	$\phi_4(\hat{x}_4)$	$r_{55}^{cp}(t)$	$\phi_5(\hat{x}_5)$	$r_{56}^{cp}(t)$	$\phi_6(\hat{x}_6)$	
135	0,075	0,425	0,025	0,425	0,125	0,425	0,050	0,425	0,050	0,425	0,025
150	0,150	0,531	0,050	0,531	0,250	0,531	0,100	0,531	0,100	0,531	0,062
165	0,225	0,750	0,075	0,750	0,375	0,750	0,150	0,750	0,150	0,750	0,132
180	0,300	0,850	0,100	0,850	0,500	0,850	0,200	0,850	0,200	0,850	0,200

Table 4.26: ACWP - P3Ph5

Actual contribution of work performed - P3Ph6

t	P3QC5 0,300 $r_{66} = 0{,}200$		Weighted sum $\sum_j w_j \phi_j(\hat{x}_j) \hat{r}_{6j}($ t)
	$r_{66}^{cp}(t)$	$\phi_6(\hat{x}_6)$	
195	0,100	0,52	0,016
210	0,200	0,86	0,052

Table 4.27: ACWP - P3Ph6

Therefore, the Earned Quality of the Work Performed (EQWP) table can be built by summarising the information in the previous tables.

Activity, a_i	15	30	45	60	75	90	105	120	135	150	165	180	195	210
P3Ph1	0,001	0,003	0,009	0,015	0,022	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044
P3Ph2	-	-	-	-	0,013	0,050	0,125	0,201	0,201	0,201	0,201	0,201	0,201	0,201
P3Ph3	-	-	-	-	-	-	0,006	0,026	0,078	0,147	0,147	0,147	0,147	0,147
P3Ph4	-	-	-	-	-	-	-	-	0,062	0,243	0,243	0,243	0,243	0,243
P3Ph5	-	-	-	-	-	-	-	-	0,025	0,062	0,132	0,200	0,200	0,200
P3Ph6	-	-	-	-	-	-	-	-	-	-	-	-	0,016	0,052
$EQWP_t$	0,001	0,003	0,009	0,015	0,035	0,093	0,174	0,270	0,409	0,697	0,767	0,834	0,850	0,886

Table 4.28: Earned quality of work performed - Project 3

Thus, the QV of the project and QPI can be finally calculated.

Time	PQWS	PQWP	EQWP	QV	QPI
15	0,008	0,008	0,001	-0,007	10,42%
30	0,017	0,017	0,003	-0,013	20,28%
45	0,025	0,025	0,009	-0,016	34,93%
60	0,033	0,033	0,015	-0,018	44,65%
75	0,098	0,098	0,035	-0,063	35,65%
90	0,163	0,163	0,093	-0,069	57,39%
105	0,260	0,260	0,174	-0,086	67,05%
120	0,358	0,358	0,270	-0,087	75,56%
135	0,590	0,590	0,409	-0,181	69,38%
150	0,823	0,823	0,697	-0,126	84,72%
165	0,881	0,881	0,767	-0,115	86,99%
180	0,940	0,940	0,834	-0,106	88,74%
195	0,970	0,970	0,850	-0,120	87,61%
210	1,000	1,000	0,886	-0,114	88,58%

Table 4.29: Quality variance - Project 3

4.1.8.5 Conclusions and recommendations

The main objective of using the methodology was to provide a control tool for project managers managing R&D projects. The methodology proposed here allowed this to be carried out optimally, as it allows the definition of control points and the collection of the necessary information to achieve the control as mentioned earlier over the project.

The evaluation in terms of quality makes it easier to know, with objective values, how well the research is being carried out and, therefore, to be more sure of its development and the results to be obtained.

Similarly, the defined checkpoints and the suggestion of task evaluations based on the defined quality criteria allowed the three projects to collect the necessary information to focus on scientific publications, fulfilling one of the CSCs defined by the organisation's project team and stakeholders.

On the other hand, the feedback on the work done by the project's research team allowed for specific improvements in the tasks that were carried out without affecting the expected fulfilment of the project's schedule.

From the outset, having the CSCs defined for the project is vital for its achievement and subsequent evaluation of results, as well as stakeholder satisfaction with both the management of the project and the results.

The quality variance analysis, as well as the QPI, are of vital importance when evaluating and monitoring the project. Although for Project 3, the objectives and requirements were achieved, it is observed in the Table 4.29, that there is a deviation of -0.114 on the total quality at the end of the project. The importance of this number is not its quantity but that the methodology allows us to look back and see where the quality faltered and led to the final result.

However, we are aware of some gaps in the research.

- The criteria on which project tasks are evaluated are defined from the early stages of the project. However, this evaluation is carried out at the subjective discretion of the project manager. Experience tells us that if the project objectives are defined, and the technical and quality requirements are, an objective evaluation within these parameters is relatively easy to achieve. However, the human factor can permanently affect the assessment of the task. Therefore, methods in which subjectivity in the evaluation can be reduced should be investigated and developed for methodologies that include suggestions/commitments/evaluations by PM or stakeholders.
- The distribution of weights in the evaluation criteria (c_j) according to the method of Paquin et al. [3] suggests the use of Saaty's method [158]; however, we take a more informal approach to distributing these weights. The results are not altered using Paquin et al.'s or our method, as the technical and quality criteria are defined from the outset. Still, an intermediate approach in which critical tasks are highlighted and identified, and the development of a mathematical model for the distribution of task weights based on these criteria, would help bring the two approaches closer together.
- Despite the complexity of managing R&D projects, the complexity depends entirely on the TRL at which they are targeted. The methodology proposed here works well for high TRLs, where the nature of the research is more tangible than in the first TRL levels (1 to 4). The next step would be to apply the methodology to these TRLs and determine whether, with proper documentation of past projects, plus the definition

of technical and quality criteria, the results of these projects can be improved using the methodology.

- Project risk management is as important an activity as quality assessment throughout the project life cycle, and they complement each other. Proper risk management will increase the quality of the results and vice versa.

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Part II

Conclusions

5

Conclusions and future research.

5.1 Conclusions.

The conclusions that can be reached after carrying out the different studies discussed above are as follows:

1. The use of EQM to manage R&D projects, as reflected in the proposed methodology, is excellent for controlling these projects as it allows monitoring and evaluating tasks against the overall project objective, as well as making decisions at critical points in the project and adapting management according to changes that arise.

2. The analysis of the TRL level at which the project is developed provides the opportunity to improve the setting of objectives and the choice of project management techniques and methodologies to achieve them.

3. UIC projects are vital for dynamising the economy and research at local, regional and national levels. Thanks to the proposed project management methodology, it was possible to improve the results achieved.

4. Despite the fuzziness of the term, applying statistical techniques to determine project success within organisations and their stakeholders is vital for a correct evaluation of project results and strengthening collaboration agreements.

5.2 Future research.

1. About Project Management:
   - 1.1 The management of R&D projects requires an analysis of their characteristics, inputs and outputs from a systems perspective. Integrating these concepts, equating an R&D project with a dynamic system, will be of vital help in understanding the phenomena that occur while managing such a project. It will also provide clues as to where and why problems occur and the possibility of proposing solutions to the problems encountered.
   - 1.2 Research into the description of hybrid project management methodologies and practices should be continued, as it allows practitioners of the discipline to take the best of each approach and use it in their project, but without falling into the requirements of each of these approaches. Beyond building an approach or a new methodology, PMs should have a battery of approaches and methodologies they can apply to specific problems in their projects. Awareness of their usefulness and the ability to use them correctly in their projects should be a line of research in the coming years.
   - 1.3 Again, there is no one-size-fits-all solution regarding a unified methodology for project management. However, finding practices easily applicable to PM for management improvement should be a line of research to be explored by practitioners and researchers in the discipline.
2. About TRL:
   - 2.1 To investigate and develop strategies focusing on technology transfer in TRLs 5 to 7 in which communication, compliance, knowledge transfer and information transfer are managed through a project management approach; since, according to the research developed, the scientific literature shows that collaborative research projects are composed of very heterogeneous activities and management conditions.
3. About UIC:
   - 3.1 Collaborative research projects require extensions and adaptations of existing project management knowledge and require specific guidelines, tools and techniques adapted to the special needs of this type of project. Therefore, the creation of practices aimed at improving the effectiveness of projects funded by regional, national and European public and private entities through big data analysis of the results obtained from these projects versus the given funding; a literature review and structured surveys to PMs on best practices for technology transfer from university to industry; and a study to find and typify the main drawbacks

in achieving the results proposed by the projects.

4. About Artificial Intelligence for Project management:
   4.1 The use of artificial intelligence techniques for analysing project information in search of insights allows the classification, analysis and classification according to defined criteria of the tasks performed in the projects. The methodology proposed in this thesis provides vital information for predicting project performance in search of the optimisation of resources through improvements in the scheduling of tasks.

5. About CFAA
   5.1 A project plan should be prepared to ensure that the KPIs are correctly applied in the CFAA, as well as a way to monitor their efficacy in the organisation. Furthermore, the integration of information from many parts of the organisation (Internet of Things (IoT), edge computing devices, project reports) must be ensured to determine the correct operation of the KPIs. This is an equally crucial process as developing the KPIs themselves. Thus, using dashboards, scorecards, and reports that present information in near real-time is strongly advised.

6. About Success Factors:
   6.1 Seek strategies that focus on reducing the complexity of measuring, identifying and controlling project success criteria.

Part III

Appendix

This section presents some of the papers published according to each of the topics developed during the thesis. The rating (where applicable) is also attached according to the Scopus web page [1] during the last five years in relation to the subject of the present thesis.

[1] Scopus Sources - https://www.scopus.com/sources.uri - Last Access: 20/12/2022

6

University - Industry Collaborations.

Progress in research, development and innovation processes can only be understood with the participation and exchange of knowledge and technology with universities and companies from different sectors. This not only leads to a growth of local R&D&I, but also allows the participants to achieve goals proposed at governmental and European levels to improve competitiveness to be active players in Industry 4.0.

From the beginning, we were concerned about how these collaboration strategies were generated, how they were dynamised, what characteristics they had and how the results could be achieved from a project management approach. Therefore, two publications were developed in this line in which we analysed different elements of this type of collaboration, such as the search for common elements between innovation clusters, the search for collaboration patterns and the analysis of the description of competence profiles based on the demands of R&D&I projects.

The publications mentioned are listed below.

6.1 CP. 1 - Conference Paper.

Pinilla, L. S., Bengfort, S., Mikhridinova, N., de Lacalle, N. L., Wolff, C., & Gandarias, N. T. (2020, March). Patterns for international cooperation between innovation clusters. Cases of CFAA and ruhrvalley. In 2020 IEEE European Technology and Engineering Management Summit (E-TEMS) (pp. 1–7). IEEE [6].

In the link to access the article, in the section on "Request permission for reuse"[1], it says: "The IEEE does not require individuals working on a thesis to obtain a formal reuse license"[2]

[1] https://ieeexplore.ieee.org/document/9111695 - Last Access: 20/12/2022
[2] https://tinyurl.com/mr285wpu - Last Access: 20/12/2022

Patterns for International Cooperation between Innovation Clusters. Cases of CFAA and ruhrvalley

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***Abstract*—Initiatives such as "Industry 4.0" in Germany and "Basque Industry 4.0" in the Basque Country (Spain) have been helping companies to be competitive in the fast-changing environment and evolving markets. However, it would not be possible to achieve those goals without a close collaboration between applied research enabled by Higher Education Institutions (HEI) and companies from different industries. This collaboration contributes significantly to research, development and innovation processes facilitated by the exchange of knowledge and technology. Innovation clusters like CFAA (Zamudio, Spain) and ruhrvalley (Herne, Germany) are successful cases of collaboration strategies between industry, HEIs and government. Even though the first research partnership focuses on advanced aeronautical manufacturing, and the second one on renewable energy and electromobility, they share the same scope of research, development and innovation (R&D&I) projects realisation. Therefore, these R&D&I institutions share the common language of project management in the field of Industry 4.0. This article focuses on the systematic analysis of common elements of two innovation clusters and the finding of patterns towards collaboration between them, which can lead to the improvement of local ecosystems of the involved parties.**

Keywords*—*innovation cluster, international collaboration, R&D&I project management, triple-helix-systems

I. Introduction

The Ruhr Valley and Basque economies have undergone major transformations in recent decades. Several economic crises had been overcome thanks to efforts made by Federal and local governments, different companies and social agents, which allows adapting to challenges presented by the new economy since 1990. Moreover, important efforts have been made through strong investment on transforming these regions from industrials driven to modern, innovative, competitive, and high-quality educational ecosystems, with a big focus on sustainability, new needs of the industry, efficient and modern mobility, and clean energy consumption.

Porter [1] in his study of the close relationship between capabilities, innovation and development concluded that territories need to develop innovative strategies that lead them to build competitive advantages based on their existing resources, skills, capacities and trends. Various diversification strategies supported by local governments pursued the transformation of the economy based on competitiveness through efficiency, to one based on innovation.

According to UNE 166001:2006 [2], innovation is the application of new or significantly improved methods, techniques or supplies in any activity whose objective is to obtain new products or processes or significant improvements in existing ones. However, it can be argued that there is a lack of agreement in the academic literature about why, where, and how it takes place. [3]

Innovation is not an isolated process, and it is dependent on a complicated mixture of factors regarding economic circumstances, company maturity level, government support, universities capacity for R&D&I processes, and access to qualified personal. Initially, it was largely seen as an activity carried out by individual innovators, e.g. companies or universities as isolated bodies. Nevertheless, recently innovation processes have become increasingly complex due to joint effects of pressure on:

- industry, where faster technological evolution, need to compete in international markets, and shorter product life cycles happen,
- university with demanding growth in practical knowledge and fulfilment of broader social remit,
- research centres with issues on technology transfer, rising funding for new research activities and equipment, theoretical and practical knowledge generation.

Therefore, the innovation process can be seen yet as the mutual efforts of these agents. As a result, this collaborative process has also helped to create innovation clusters of interacting companies. HEIs and local governments, in terms of product-supplier relations, access to tacit and explicit knowledge and labour supply intending to enhance the innovation among local companies and become a sustainable source of practical knowledge for all their members and a way to boost the technology exchange.

Two successful examples of research associations are the ruhrvalley innovation cluster in the Ruhr region of Germany,

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and Aeronautics Advanced Manufacturing Centre (Spanish: CFAA) in the Basque country of Spain. Regardless of their focuses on technologies of different Technology Readiness Level (TRL), these two clusters share the same scope of R&D&I projects realisation in the context of Industry 4.0 and a similar structure of local integration and collaboration. Through collaboration activities between these innovation ecosystems, the process of innovation projects realization can be significantly improved and therefore, beneficial to the involved parties of the research centres.

II. Research Questions And Methodology

To establish a proper and working collaboration, a profound strategy is required. This strategy will be formulated based on the next case formulation: CFAA and ruhrvalley are the innovation clusters, which have their own needs for R&D&I project management. The needs analysis will be formulated based on the analysis of the "as-is" situation derived from a description of both research associations and interviews of speakers and parties involved in the management of these clusters. A joint needs analysis will form a common need for cooperation (Fig. 1).

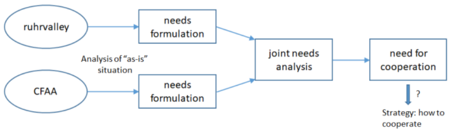

Fig. 1. Case formulation

Based on the formulated case, the next questions tend to be replied: (1) should technology clusters cooperate cross border and why; (2) if there is a need to cooperate, how this cooperation should be maintained. To reply to the second question, we will address best practices within state of the art of international cooperation strategies in research.

As a result, we pursue an aim to formulate general recommendations for cooperation between technology clusters within Europe. Process of cooperation of the complex innovation ecosystems requires an elaborated strategy, which will be stated in this paper based on a systematic analysis of each of these innovation clusters (Chapter III), a definition of common elements (Chapter IV) and a formulation of key actions to be taken (Chapter V).

III. Systematic Analysis Of Two Innovation Clusters

A. *ruhrvalley research association*

With more than 5 million residents, the Metropolis Ruhr is the third-largest metropolitan area in Europe along with Paris and London. Due to its coal and steel industry's history, the region has grown into a highly urbanized urban area. The steel industry still plays an important role in terms of energy consumption [4]. Given the fact that the core competencies in conventional, fossil energy supply are regionally bundled, an extensive grid-connected energy supply infrastructure was created [5]. Also, the metropolitan region of the Ruhr Valley has one of the densest road networks in Europe with approximately 4,700 km of cross-regional roads, which are mainly used for short-distance travel and transport. Transport is with a share of more than 30 per cent of primary energy consumption a significant factor in the consumption of energy in Germany [4].

The German energy system is transforming into a decentralized, heterogeneous system – notably in the metropolitan region of the Ruhr Valley. This leads to the coupling of sectors, e. g: electricity and heat grids, traffic (like eMobility), industry and housing. Taking into account that network systems and the complex mobility and energy challenges cannot be solved by isolated approaches, Bochum University of Applied Sciences, Dortmund University of Applied Sciences and Arts, and Westphalian University of Applied Sciences joined their forces to become a transdisciplinary research and innovation network several years ago.

In 2015 these universities along with other players located in the Ruhr area participated in the competitive funding programme "FH Impuls" by the German Federal Government. Ultimately ruhrvalley was one of the ten winning clusters in the competition. The government's monetary input (8-year-plan with 10 Mio. EUR and several Mio. EUR industry funding) is now used funding and implementing several research projects in order to intensify collaborative work between universities and industry, to create innovative solutions and generate new projects that ultimately lead to business ideas and start-up formation. This was the birth of " ruhrvalley – Mobility & Energy Systems for Metropolitan Change".

At present, ruhrvalley contains three large universities of applied sciences (Bochum University of Applied Sciences, Dortmund University of Applied Sciences and Arts, and Westphalian University of Applied Sciences), seven of their research institutes (44 professors, 170+ scientific staff in R&D), 24 spin-off companies and 100 associated and project partners [6]. The innovation cluster ruhrvalley covers the research areas of electro-mobility, energy system technology and geothermal energy, information and communication technology, IT security and all areas of economic and social sciences and applied innovation research. Collaboration in ruhrvalley works on a projected level in different project formats and with various partners from electric mobility, energy systems, digital transformation involved (Fig. 2), claiming "Mobility and Energy for Metropolitan Change" [7].

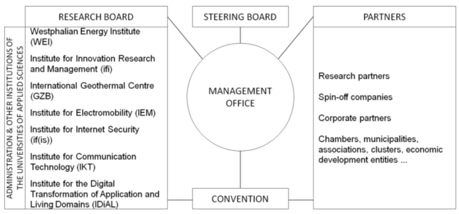

Fig. 2. ruhrvalley management structure [8]

The innovation cluster ruhrvalley applies a holistic system engineering approach (Fig. 3), which aims to integrate the subsystems and processes of innovation management and product development into one procedure.

Through implementation-oriented R&D results, and this extended understanding of innovation in order to allow networking, interactions and feedback loops along the entire value chain ruhrvalley promotes innovative entrepreneurship and therefore follows the recommendations for structural change in the Ruhr region [10]. As a result, ruhrvalley is likely to make a significant contribution to the reorientation of the

Ruhr Metropolis to technology and knowledge-oriented SME region. The highest university level in Europe and the growing start-up and start-up scene make this region an internationally attractive location for innovative companies.

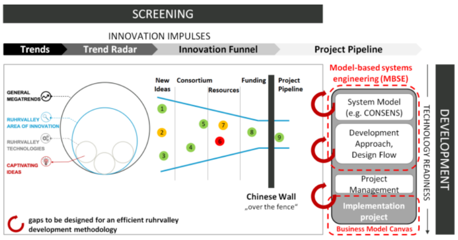

Fig. 3. ruhrvalley system engineering approach (based on [9])

B. *Centro de Fabricación Avanzada Aeronáutica (Aeronautics Advanced Manufacturing Centre) – CFAA*

To cover new needs of the Basque industry, the support from the local government to vocational training programs has been boosted in order to develop the skill-set needed to answer the demanding challenges of the Industry 4.0 [11].

The growing investment by the Basque Government on R&D (Fig. 4) and digital transformation of the region is led by the Basque business development agency – SPRI Group, where companies can obtain financing, locate industrial land, apply new technologies, innovate or carry out a necessary process of entering the new industries [12].

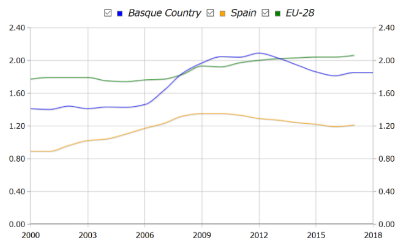

Fig. 4. Evolution of the expenditure on domestic R&D concerning GDP [16].

The R&D&I structure is formed by basic, applied and sectorial research centres with strong relations to universities and local companies. The Basque university system is distributed in three different public and private universities and formed by around 70.000 students, 24.1% of them study engineering and architecture [13]. Some of the most important local research centres have been reunited under a new structure supported by the Basque Government called Basque Research and Technology Alliance – BRTA [14], intending to generate a dynamic of cooperation and to unite forces to confront the industrial challenges faced by the Basque Country.

In this context, in 2017, the CFAA was assigned the goal of developing advanced manufacturing technologies and working around TRLs 5-7 [15]. The joint bid between the grouping of aeronautics companies and the machine-tool sector in the Basque Country, with the initiative of the Department of Economic Development and Infrastructures of the Basque Government and the Bizkaia Provincial Council, plus the University of the Basque Country, is already reaping its fruits.

The CFAA is a new model designed to foster relations between companies from two sectors and in the university-business axis [17], also highlights the collaboration between machine-tool manufacturers and Tier 1 and 2 businesses in the aeronautics engine sector. The first of these is in charge of carrying out research on new processes and developing specially adapted machine tools to improve productivity, quality and precision, while the latter is working on developing new engines.

A Rector Committee, who defines lines of action, composition, structure and operation of the Centre, carries out the management. In its turn, the Technological Committee is in charge of promoting and developing the objectives of the Centre, as well as approving or not the realization of projects according to the lines marked as priorities, and the sought of intensive use of resources.

The management and control of the projects (innovation, R&D and R&D&I projects) are carried out by personnel assigned by the Director of the Centre (Fig. 5). Currently, CFAA is working on the implementation of a project management methodology developed ad hoc for the Centre, whose objective is to manage projects, programs and portfolios, and push the organization toward more agility and efficiency [18].

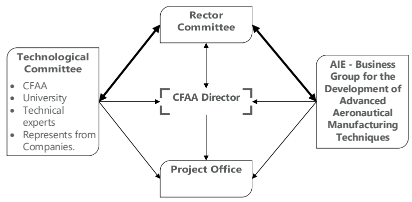

Fig. 5. CFAA management structure.

The mission of CFAA can be summed up as a promotion of collaborative research and development in the field of aeronautics manufacturing technologies, the performance of activities that enable a quick transfer of results to the production setting associated to the value chain. The Centre aims at attracting innovative initiatives in the field of advanced aeronautics manufacturing that can develop and generate a new regional industrial network or bolster the existing structure. With taking advantage of the synergy of the university, the companies and the institutions, the Centre focuses efforts on developing R&D&I and educational activities geared towards technologies of interest for Basque industries and develops scientific-technological skills in the field of advanced manufacturing.

Nowadays, the CFAA is formed by more than 25 researchers, including whose who is completing their PhD, as well as responsible for the project's and research lines coordination, 8 professors from the University, more than 20 employees of partner companies working on Centre's research projects, and 7 more are in dual training for partner companies. Also, there is a total of 78 partner companies [19]. The partners' commitment includes undertaking projects at the centre and working together with others, with their related expenses. Excellence and a good predisposition for collaboration are the main considerations for partnership selection.

To date, over 200 projects have been carried out, with a success rate close to 79%, which means that the results obtained are being used by aeronautics companies and machine-tool and cutting tool manufacturers. This high success rate is explained by the close cooperation between technicians, researchers working in the centre, and staff from the involved companies who are in constant contact with the workers. This helps to prevent wrong pathways taken at the early stages of the research.

The impact of the university's manufacturing groups is also significant: in two years, 7 industrial doctoral theses have been developed, and over 20 scientific papers have been published.

IV. Why and How to Collaborate Internationally?

Collaboration between innovation clusters is intended to improve innovation in the economy by facilitating the flow and use of technology-related knowledge and expertise across sectors [20]. This sum of capabilities can serve to create knowledge that none of the participants had before, through the interaction between actors during the collaboration lifecycle.

Both innovation clusters are built based on a Triple Helix model, involving elements of academia, industry, and state, a balanced intersection of which creates the best environment for innovation in a knowledge society [21, 22].

The survey conducted within academia, higher education institutions in Africa, Asia Pacific, Europe, Latin America, North America and the Middle East, highlighted three the most likely areas of future growth: international institutional agreements and networks, outgoing mobility opportunities for students and international research collaboration. Moreover, the same survey pointed Europe region as the most attractive for international cooperation [23].

A case of the internationalization agenda in the UK summarizes three stages of international strategies development: international activity, strategy, and internationalization process. International strategy stage considers centralized coordination and alignment of different agendas. Effective leadership, communication and centralized management approaches are seen as the ways to improve internationalization [24].

Among international research cooperation activities [25] lists joint research projects and studies, organization of workshops, conferences, and symposia, as well as multi-lateral visits and information or personnel exchanges. From a management perspective, the author points out that research cooperation should have clearly stated functions: strategic management, research performing and capacity building, programme monitoring and funding, implementation and market uptake of research results. Under the capacity building, the elements of human capital, research infrastructures and research teams are considered, which will carry a necessary work in cooperative bids and projects [25].

From the cooperation in industry perspective, [26] highlights that those companies cooperating across national borders would be able to compete globally. The author distinguishes three main goals of international strategic cooperation: scale advantages by combining similar capacities, resource advantages by combining complementary capacities in the form of special skills and strengths of partners, and learning advantages when cooperation itself serves a means for enhancing and internalizing new skills. Moreover, [26] underlines that success of international strategic business cooperation depends on situational conditions (the higher the degree of industry concentration, the more successful the cooperation is), performance criteria (special indicators should be developed to measure the success of this cooperation), and management instruments.

Lazzarotti [27] using a balanced scorecard, proposed a model for performance measurement in R&D projects, grouped in five perspectives: financial, customer, innovation and learning, internal business, alliances and network perspectives. The last perspective is supposed to be measured by several employees involved in external relations, percentage of projects applying design for assembly, and numbers of partnerships dedicated to technological innovation [27, p. 217].

Focusing only on international strategic cooperation, [26] proposes to supplement traditional performance indicators by criteria of harmony, morale, adaptiveness, which cover measures of qualitative satisfaction, and how objectives of cooperation are met; those elements reflect the joint usage of resources and strategy in general. Among management instruments [26] underline partner selection, based on strategies, resources, and corporate cultures compatibility, as a key success factor of cooperation. A second success factor is seen as a cooperation agreement, which should be carefully prepared to be used when conflicts arise.

An adapted version of the Mitsushashi model for business-to-business alliance formation [28] can light the way on how to develop an agreement. The first step consists of the identification of the cooperation, in which the purpose of the collaboration strategy must be settled and the identification of the capabilities (facilities, research, expertise) achieved. Secondly, a cooperation assessment, where is needed an objectively assess of strategic interests and an analysis of actual vs hidden capabilities. In the third step, the mission, vision, goals and/or objectives, and the structure and responsibilities of the cooperation must be defined. Milestones and identification of the KPI's should be consumed along with the specification and definition of the deliverables. Moreover, for the last step, preparation and signing of the cooperation agreement and/or intellectual property agreement must be achieved.

Moving further to global competitiveness, [29] point out that international cooperation is a leverage tool towards competitive advantages of involved countries, what links to a value-added chain specifically in R&D field: e.g., a company can have years of experience with traditional technology but no competence in the new one. Therefore, country-specific advantages are seen as motivators of internationalization. [30] refers to a country's competitive advantages to capabilities for innovations generation and effective usage of technology. [31] claim that besides competitive advantages, strategic alliances can achieve synergies in knowledge and experience combined, that are expensive and slow to be built internally.

[32] proposed a model for research internationalization (Fig. 6) considering strategic matching as a means of comparing missions of involved research entities. Contextual factors, in this case, focus on research infrastructure and fields

of study, whereas institutional factors are defined by available resources and technologies, and governmental support refers to relations between involved countries.

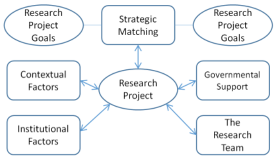

Fig. 6. Model for the internationalization of research (based on [32]).

It should be noted that collaboration between innovation clusters brings several benefits and drawbacks for both parties. According to the study [33], benefits can be classified into the next categories:

- economic: contribution to local/regional economic development, creation of business opportunities, joint search for funding (public and private),

- institutional: quality and number increase of publications, access to modern facilities, stimulation of development and creation of research activities in related areas, exposure of researchers and students to practical problems or new ideas and/or cutting-edge technology, feedback of research ideas, joint analysis of results or interpretations for refinement,

- social: enhancement of the reputation of innovation clusters and display of results of public investment received).

The drawbacks can also be summarized in terms of quality (diversification of activities can affect the performance and commitment of researchers through exposure to new and different problems), conflicts between researchers and companies (due to the publication of inconvenient results or reports biased by different interests of the projects' stakeholders), and risks associated with the publication of results.

V. Defining Common Needs and Functions of Collaboration

The efficiency of collaboration between universities and industry is an important issue for policymakers, due to the need to ensure that the results of the research can be transferred to industry quickly and effectively so it can contribute to the growth and well-being of the economy [34]. That creates needs for universities to develop collaboration strategies not just with industry but also with local and international innovation ecosystem. The collaboration can be seen as a means to improve innovation efficiency and enhance wealth creation and to enhance the universities' prestige [35].

Each of the innovation clusters is distinguished for carrying out serious, multidisciplinary, specialised, result-oriented research (in the form of applied knowledge, adaptation, process or product development), which are transferred to the companies involved in one particular project in the shortest possible time, integrating different companies, universities and research partners along the way. The fact that Ruhr valley and CFAA belong to different industries does not become a difficulty in overcoming, but an opportunity to obtain an external, objective and specialized point of view that may help to improve the development and results of the projects.

After a systematic analysis of the "as-is" situation based on the model [32], it can be concluded that the clusters have the next elements in common:

- Strategic matching: strategic goals within research and innovation fields are the same: "to increase an impact of R&D results in the scientific community", "to create and commercialize new service offers" (based on strategic goals within scorecard of ruhrvalley and strategic plan of CFAA),
- Contextual factors: the regional focuses of clusters are the same since they are located in industrial urban areas being digitally transformed through technology-, and innovation-driven approaches [4], [11]; technology readiness level of research projects: TRL6-7 [7], [17], [15]; focus on Industry 4.0 technologies [11].
- Institutional factors: partnership and management structure of both clusters is based on the Triple Helix model [8], [18].

Governmental support of research collaboration is assumed to be already at a place since both clusters are located in Europe and can be supported further with common European research bids and later projects [25]. Moreover, differences in the focus areas of innovation clusters add value by compensating capacities of each other in case of applying for joint project calls.

Furthermore, based on the framework for a sustainable multilateral international research cooperation developed by [25] we formulate functions and propose supportive activities to address common needs of innovation clusters (Table I).

A practical example of a collaboration case can be the Additive Manufacturing (AM) technology. CFAA has the equipment, trained personnel and wide experience in the research field and development of this technology, as well as the Dortmund University of Applied Sciences and Arts (partner within the ruhrvalley cluster) has its laboratory based on the Mechanical Engineering department. AM allows the creation of three-dimensional pieces from a digital file. One of the AM processes is Selective Laser Melting (SLM), a process in which thin layers of material are melted by a laser to create complex shapes that cannot be produced by traditional manufacturing techniques. Its main advantage is to reduce material use and tooling costs and increase design possibilities. Due to its great versatility, AM is being used in the aerospace, automotive, medical and healthcare, heavy industry, precision manufacturing and energy industries [36]. The CFAA is developing studies to extend its experience in processes of simulation of Laser Melting Deposition (LMD), a study of powders for SLM, manufacture of complex structures by SLM and LMD, and quality processes [37]. The partner of ruhrvalley mostly uses their laboratory for the study purposes in a range from the examination of manufactured components and their areas of application and the analysis of additive manufacturing processes to process optimization and further development of the machines as a sound base for digitalization processes [38]. Collaboration on joint research activities based on the AM technology will fulfil the need of building new value networks, and by exchanging researchers from the partner clusters, the number of personnel and capacities available to carry out joint R&D&I projects will be increased.

TABLE I. FUNCTIONS AND APPROACHES OF COLLABORATION FRAMEWORK

Function	Common Need	Supportive Activity
Strategic management	1. Initiate and increase collaborative projects with research partners within university and technology centres. 2. Build new value networks. 3. Increase the number and weight of alliances reached with different R&D&I centres worldwide.	1. Training and development of talents, initiation of joint ventures, acquisition of venture capital, coordination of cooperation with chambers, associations and business development agencies, recruitment of innovative start-ups and joint ventures. 2. Targeting potential new partners and introducing the innovation clusters, signature-ready coordination and negotiation of cooperation agreements, preparation and implementation of strategy talks with partners, conception and implementation of a partner relationship management. 3. Defining procedures to identify common research interests and formulating work programs.
Research performing and capacity building	1. Increase the effective use of (shared) resources available in each of the innovation clusters; increase the number of projects executed with the support of SME's and partner companies. 2. Increasing the number of personnel and capacities available to carry out joint R&D&I projects. 3. Reducing the time of implementation and life cycle of the project. 4. Increase the number of training hours (staff and partners)	1. Establishing strategic alliances with international partners to add material and intellectual resources for a better success rate of approval of applications to European project calls. 2. Initiating and carrying research projects with international partners for recruitments or exchange of researchers; based on strategic planning; proposing coauthored works in high standard and quality of research communication. 3. Managing a strategic project in cooperation to obtain a better performance of the resources available. 4. Widen the range of possibilities to promote knowledge about the processes or results achieved in the projects; networking events carried out at innovation clusters.
Programme monitoring and funding	1. Search for processes and tools that help to mitigate the risk of failure during the development of the projects. 2. Find and develop the competencies needed to manage the interdisciplinary projects. 3. Increase the number of applications for funding through European projects calls.	1. Sharing tools for monitoring indicators of the project lifecycle. 2. Establishing strategic alliances with international collaborates for recruitments or exchange of researchers; establish a training program according to the strategic research lines and common project perspectives. 3. Defining strategic planning according to initiatives proposed and implemented; define the strategic alliance governance and approaches for developing and managing research programs.
Implementati on and market uptake of research	1. Increase the number of networking events 2. Increase the number of published papers on top-field scientific journals, conferences, workshops	1. Participation in events with potential partners for introducing the innovation clusters and sharing projects results. 2. Co-authoring joint research papers in high-indexed journals based on the agreed research plan.

VI. CONCLUSIONS

This paper aimed to study the possible collaboration patterns between ruhrvalley and CFAA and show how with the knowledge and expertise gained from projects, the innovation clusters can improve their capabilities and help their partners through a faster and better-applied knowledge and a new set of skills. Joint bids through international collaboration can improve relations between expert knowledge of both parties, and help to connect the regions innovation ecosystems.

With the actual need of the innovation clusters to gain competitive advantage, improve efficiency and show valuable, positive and fastest results, collaboration this kind of agreements can help them to speed up the innovation process. However, important challenges must be overcome: lack of balance (in terms of capacities to do valuable research), different institutional cultures. To face them, objectives must be settled from the beginning, as well as clear governance structures must be defined.

Moreover, this paper could be valuable for those innovation ecosystems who search for establishing relations with similar clusters based on the same Triple Helix model, developing urban areas into technology- and innovation-driven but focused on different industries.

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6.2 CP. 2 - Conference Paper.

Mikhridinova, N., Pinilla, E. L. S., Bengfort, S., Wolff, C., de Lacalle, N. L., & Gandarias, N. T. Building Cooperation between Innovation Clusters Based on Competences Requirements. Case of CFAA and ruhrvalley. Research and Education in Project Management (Bilbao, 2020), 21 [7].

3rd International Conference on Research and Education in Project Management – REPM 2020

Building Cooperation between Innovation Clusters Based on Competences Requirements. Case of CFAA and ruhrvalley

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Abstract: The paper presents results of the joint research between CFAA (Spain) and ruhrvalley (Germany) innovation clusters regarding the competence profiles description based on the demands of R&D projects. Both research bodies are based on the triple helix model involving participation of higher education institutions: CFAA is the part of the University of the Basque Country (UPV/EHU), and Dortmund university of Applied Sciences and Arts (FH Dortmund) and Westphalian University are ones of partner universities involved in ruhrvalley project. Research lines of these innovation clusters have different focuses but several elements in common. A current cooperation between those innovation ecosystems works on the level of universities mostly thanks to the funding possibilities to support mobility activities of master and PhD students. Considering previous experiences with exchange students, further it will be reflected how this cooperation can be improved and extended on the level of involved innovation clusters. Analysis of semi-structured interviews with researchers and managers of research bodies will contribute to description of competence profiles required to work on joint R&D projects.

Keywords: competence; innovation cluster; research collaboration; triple helix model

1. Introduction

Innovation clusters CFAA (Aeronautics Advanced Manufacturing Centre) and ruhrvalley are located in the Basque country of Spain and in the Ruhr region of Germany, respectively. Both innovation ecosystems are formed by a triple helix model, which involves a balanced intersection of academia, industry, and state, to create the best environment for innovation in a knowledge society [1]. Namely, ruhrvalley cluster is formed by three large universities of applied sciences, seven of their research institutes, spin off companies and associated project partners [2]. The innovation cluster ruhrvalley covers the research areas of electro-mobility, energy system technology and geothermal energy, information and communication technology, IT security and all areas of economic and social sciences and applied innovation research. CFAA is a research centre within the University of the Basque Country (UPV/EHU) and a consortium of companies, with the aim to deliver final applications and to generate new know-how in advanced manufacturing technologies [3]. Both research bodies if cooperated, could improve innovation processes by enhancing the "collaborative" sum of capabilities that none of the participants had before. One of these capabilities is competence capacity of researchers.

In order to sustainably strengthen the research priorities at universities and the development activities of SMEs within the ruhrvalley network, a structured concept for human resource development is planned to be developed and implemented. This intends to provide scientific support for personnel qualifications in the partner companies, especially for start-ups and spin-offs. At the same time, efforts are being made to increase staff qualifications in the research institutes (including project management, social skills). Transfer via heads will revitalize teaching and provide universities with attractive offers for graduates and doctoral candidates.

Previously, four master students from FH Dortmund have already accomplished their internships and research stays on the base of CFAA, what was possible due to existing agreements between UPV/EHU and Dortmund university of Applied Sciences and Arts (FH Dortmund). Two of these master students had a background in applied mathematics and industrial engineering, what helped to contribute significantly to research in evaluation of success factors of R&D projects. Other two master students were experienced in quality management and mechanical engineering subjects.

As the outcome, five research papers were delivered and accepted for further publication, as well as three project theses were developed on the next topics:
- new methodology for R&D and innovation project management,
- decision making based on qualitative data,
- evaluation of the maturity of the planning processes related to the scheduling and estimation of the projects in the context of multi-project management.

For the CFAA, the exchange of ideas, different approaches to research problems solving, high quality of the results obtained, the knowledge

acquired, and cultural exchange are seen as valuable inputs to pursue sustainable outcomes of that collaborative research work.
Based on previous experiences with the exchange students, semi-structured interviews with the manager, coordinator of research projects and technicians / researchers of CFAA, and coordinator of ruhrvalley will highlight which competences are required to collaborate on joint R&D projects.

2. Research Methodology

In the current research, we applied a bottom-up research strategy to reflect the collective view towards individual competences [4]. Technicians and researchers at CFAA were interviewed regarding one of three specific technologies, for which they were responsible (group 1). Those three technologies are: additive manufacturing, advanced machining of integral rotary components, and validation of digital X-ray technology for aeronautical components. Interviewees of this group presented an experience within CFAA as of one till three years, and in similar positions – between one and 1eleven years.

Coordinator of research projects in all three domains was asked to provide the overview of the required skills for working on projects (group 2). Experience of this group counts three years at CFAA, and thirteen years in similar positions.

Further, the manager of CFAA and coordinator of ruhrvalley provided their expert opinions (group 3) as an overview of demanded competences including those required to manage R&D projects. Manager of CFAA has five years of experience in the actual position and more than ten years in similar positions, whereas the ruhrvalley' coordinator's experience counts for two years in experience in the actual position and more than six years – in similar. An overview of research methodology is presented in the *Figure 1*.

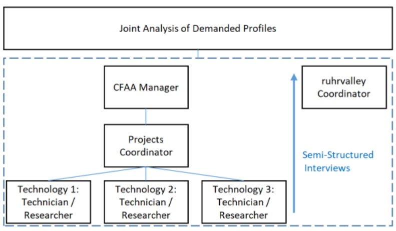


Figure 1. Research methodology.

Moreover, with the help of literature research next questions attempt to be replied:
- what is meant by collaborative competences on organizational and individual levels?
- which competences will be required for future engineers in general and, particularly, to work with mentioned above technologies?

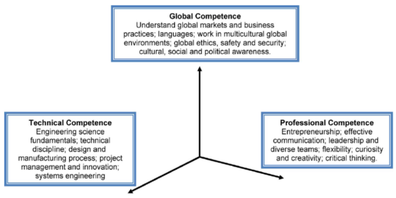
3. Literature Research

3.1. Competences to Collaborate

In 1998, [5] identified three types of competences: common, complementary, and collaborative, which is required to collaborate between organisations. [6] proposed that a collaborative advantage could be achieved through linked competencies, which help to build and maintain "network-based intellectual, human, social, political, and cultural capital". These competencies considered on the level of organization authors categorize as distinctive (difficult to be replicated by competitors), core (crucial to company's success), and core distinctive (important for reaching stated goals and long-term company's success).

On the level of individual competencies, [7] identifies twelve collaborative competencies which then form a competency model of effective executive collaborators. The scholar claims that the most critical collaboration factor is interpersonal understanding "which only comes through time and experience" [7, p. 118].

Since we consider prospective cooperation, it is interesting to highlight competences required for future engineers. It is claimed by [8] that for being competitive, tomorrow graduates would need to demonstrate technical, professional and global competences (*Figure 2*).



Adapted from Y. Chang, D. Atkinson, and E.D. Hirleman, "International Research and Engineering Education: Impacts and Best Practices," *Online Journal for Engineering Global Education*, Vol. 4, Issue 2, 2009.

Figure 2. The 3-D engineering professional [8].

Moreover, [9] provides next attributes of the global competence:
- exhibit a global mindset,
- appreciate and understand different cultures,
- demonstrate world and local knowledge,
- communicate cross-culturally,
- speak more than one language including English,
- understand international business, law, and technical elements,
- live and work in a transnational engineering environment,
- work in international teams.

3.2. Technologies Description

Additive Manufacturing (AM) is a technology that allows manufacturing of physical components from virtual 3D computer models, with a different range of materials in a layer-by-layer approach, until the part is complete [10]. The thickness of the layer depends on the technology used or the aim of the piece, with more thickness, better surface quality can be achieved. One of the most important technologies of AM is a Selective Laser Melting (SLM), which uses laser as a power source to sinter powdered metals for producing solid structures. The application in aerospace industry is being tested due to the needs of reducing fuel consumption and emission of CO_2 and NOx, and manufacturing of light weight components for engines and structural parts of aircrafts [11].

Advanced machining of integral rotary components is an important step in production, which is needed to achieve the final shape of the piece; through it, demanded dimensional and surface tolerances can be obtained. It is a complex process, which can be reached through a correct combination of right machining processes, cutting tools and conditions, and the machine tool that will facilitate the high speed needed to machining a difficult-to-cut rotary components of aero-engines [12]. Mainly, three advanced machining processes are: thermoelectric, mechanical, and electrochemical or chemical machining. None of these processes is the best under all machining situations, hence, the selection of the proper process becomes very important [13].

X-ray industrial computed tomography (CT) is the method of using X-ray radiation to take a number of 2D images of an object in different positions around a rotation axis. Next, a 3D model of the object's external as well as internal structure is reconstructed and can be analysed trough a proper software. This allows detecting flaws such as voids and cracks, and particular analysis in materials. So far, this is the only technology able to represent visually the inner and the outer geometry of a component without the need to cut it through. Over the past decade, CT has become the only technology for industrial quality control of work pieces having non-accessible internal features or multi-material components [14].

4. Results and Discussion

Conducted interviews highlighted the next elements in common. The whole group 1 stated that they require only those skills, which are needed to work with one of three technologies mentioned. Based on the framework proposed by [8] these skills will build technical competence domain.

The coordinator of projects at CFAA (group 2) provided a list of required competences, which are:
- knowledge of technology fundamentals,
- basic knowledge of manufacturing processes,
- computer-assisted design skills,
- R&D and innovation project management,
- social skills,
- critical and creative thinking.

The manager of CFAA grouped required competences as:
- effective communication skills and teamwork,
- planning, organisation and leadership skills,
- problem solving and usability engineering,
- ability to work in multicultural and multispecialty environments,
- curiosity.

Coordinator of ruhrvalley stated that besides technical and professional skills, which are at place, the emphasis should be put to obtain problem-solving skills, project management competences, knowledge and skills to apply scientific and systematic analysis, and social skills in general.
Based on the joint analysis of demanded competences and framework proposed by [8], the next summary can be provided (*Table 1*).

Group / competence		Technical	Professional	Global
CFAA	1	x		
	2	x	x	
	3	x	x	x
ruhr-valley	3	x	x	x

Table 1. Summary of statements on competences.

A bottom-up approach of opinions collection was recommended by [4] to make useful the effect of "wisdom of the crowd", - view of community of involved researchers and technicians on individual competencies. This approach revealed that the higher position of interviewee and the more experience they had, the broader view on competences was presented. Group 1 of interviewed employees described only those technical competences needed to work on the technology and it was claimed, that the social and communication skills were not highly needed since no related issues were faced during R&D projects execution. In its turn, group 2 presented by coordinator of projects at CFAA highlighted the need for social competences and creative/critical thinking, which build a professional dimension of "3D engineering professional" [8]. Whereas group 3 presented by experienced manager of CFAA and coordinator of ruhrvalley projects defined required competences, which definitely cover all three dimensions of the used competence categorization framework.

5. Conclusion

In the age of globalization and particularly for the case of cooperation establishment, global competence would play an important role for formations based on triple helix model. Industry, academia and state parties would require project management staff and multi-skilled engineers capable to successfully implement R&D projects. To achieve that, a broader set of competences would be needed, which cannot be taught only in traditional classroom but would require a learning environment with opportunities to obtain practical experience. Both innovation clusters of CFAA and ruhrvalley provide these opportunities on the R&D projects base. Interviews conducted with different groups of involved parties highlighted various sets of competences required to collaborate on research project but also the skills, which could be trained on the base of the clusters.

Furthermore, the provided list of required competences could play a role of the check-list with an intention to select prospective students and researchers to collaborate of the possible joint projects. In that case, more interviews could be required to describe precisely prerequisites to work on the particular project, as well as assessment measures should be developed to evaluate required competences.

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7

Technology Readiness Level.

Once the collaboration strategies were analysed, we analysed the UIC ecosystem from the university's point of view. We characterised the importance of advanced manufacturing centres within the aeronautical supply chain, working in TRL 5 - 7. With this idea in mind, and from the point of view of project management, a publication was developed in which different aspects of the local and European environment for this type of centre are analysed, a comparison between existing centres is made, and guidelines are defined for the creation of centres such as these, without neglecting their role as a driving force for research and technological development.

The publication mentioned above can be found below.

7.1 JP 1 - Original Journal Paper.

Sastoque Pinilla, L., Llorente Rodríguez, R., Toledo Gandarias, N., López de Lacalle, L. N., & Ramezani Farokhad, M. (2019). TRLs 5–7 advanced manufacturing centres, practical model to boost technology transfer in manufacturing. Sustainability, 11(18), 4890, https://doi.org/10.3390/su11184890. [5].

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sustainability

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Article

TRLs 5–7 Advanced Manufacturing Centres, Practical Model to Boost Technology Transfer in Manufacturing

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Abstract: Establishing collaboration strategies with interdisciplinary networks in research is a crucial success factor for the companies in any sector, especially in manufacturing for aeronautics. In the aeronautical supply chain, Small and Medium-sized Enterprises (SMEs) lack of these types of alliances with universities and other research institutions, which could give them access to shared and specialized knowledge, may strictly limit those companies to learning from their own experience. One way to break this dynamic for industrial companies is to be an active part of research, development, and innovation centres. In this paper, a study to create new advanced manufacturing centres is presented, centres whose activities are focused on Technology Readiness Levels (TRL) 5–7. The approach is based on a project management methodology, and it is applied to the aeronautical sector in the Basque Country. An initial study of the international experience and state of the art in this type of facility, as well as an analysis of the current socioeconomic environment of the Basque Country are presented. A benchmark study was done to identify the key processes that this centre must promote for this initiative to succeed, or those areas of knowledge that can make or break the initiative. Finally, the results showed a definitive picture for establishing an advanced manufacturing centre in the Basque Country. This work lays both the foundations of knowledge in the sector and the difficulties noted, so it can serve as guidance for similar initiatives.

Keywords: advanced manufacturing research centre; manufacturing readiness level; technology transfer; project management; manufacturing industry; industrial park

1. Introduction

The aviation sector, even though it has always been distinguished by establishing highly demanding requirements on the design and manufacturing of its components, has always been just behind on some issues such as the organization of production and manufacturing, compared to other sectors such as automotive and car component making [1]. However, in design or engineering, the direct application of the developments achieved through Research and Development (R&D) was and is the mark of the sector. The development of manufacturing technologies to meet these requirements and how it would place the company's competitiveness against other global competitors is crucial, because this sector is fully globalized [2]. The current situation that productivity matters is really a keystone to achieve the short-term goal of delivering new engines or airframes for the always-growing market demand.

The competitiveness of a company can be derived through four factors [3] (Figure 1), and the technology plays a key role in creating and maintaining it. Considering that the term technology can be defined as "all the knowledge, products, processes, tools, methods, and systems used in the creation of goods or the provision of services" [4], its importance for business and competitiveness (competences such as the use of basic technologies, human resources processes, management processes and technology management processes [5]) has been empirically confirmed in several contexts and is now notoriously rising in emerging countries.

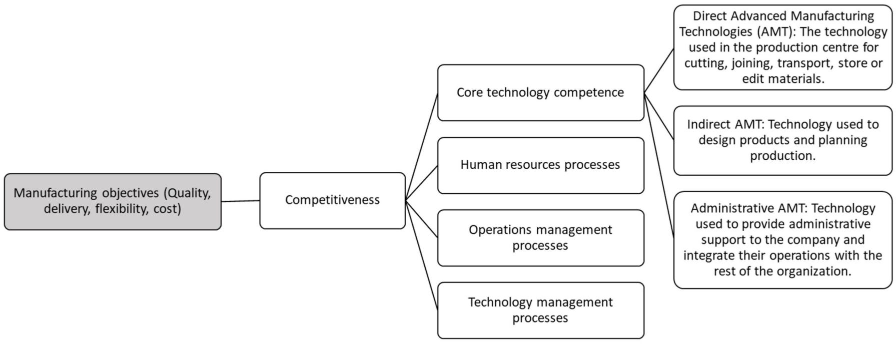


Figure 1. Conceptual network of competitiveness in the context of manufacturing.

Achieving dynamics in technological transfer about manufacturing is a demanding challenge in most companies [6]. The technology transfer process of the Basque Country in aeronautics was very high in the last decade, but it has some gaps, specifically the necessity of a place to try and test new technologies in an environment similar enough to that of the real production; this is the focus of working in the spot of manufacturing readiness level stages 5–7. There is need for a place to develop the technology to a maturity level (Technology Readiness Level (TRL) 7) and then quickly transfer the developments made by the technology agent networks, companies, and universities to the production needs of the companies. On the other hand, the collaboration of aeronautical Tier 1 and 2 companies with those providing production machines and solutions is key to accelerate any common development. Supply chain is a natural partnership for developing common projects of R&D.

The vision of a conceptual "Advanced Manufacturing in Aeronautics Research Centre" (AMARC) is to establish a place, a location, a workshop, where the local governments, universities, and industrial partners meet and collaborate and dedicate their own resources to technology transfer activities defined by the members. In this new idea of AMARC, the concentration and specialization of key technologies, previously identified by companies and universities, are essential. Along with aeronautical companies, the centre must be composed of machine tool, systems, and accessories manufacturers (trying to avoid direct competition between them) creating real synergies that allow technology developments in representative conditions of the production plants. The development should be based on a temporal scope of collaboration between the partners that ensures cost effective project completion. Those partners must decide what activities should be developed, implemented, and monitored on an ongoing basis, including physical location of companies' technicians in the AMARC in stable project teams.

Related investigations in project management of advanced manufacturing research centres have focused on how to reduce the uncertainty of the acquisition/use of a technology through a suitable management plan and proper stakeholder management (managing stakeholders in early stages is critical to success) [7]. Uncertainty reduction issues also arise to mitigate risks in the early stages of the project. The economic and organizational form of the planning and funding is also referenced in numerous articles, as well as the relationship between the adoption of advanced manufacturing technologies and investment in infrastructure [8]. This leads us to consider the qualitative and quantitative factors that can help to predict whether the initiative will be successful or not, in order to prepare the necessary actions to reach project success [9]. Some researchers remarked on the importance of collaboration between the associates of the project in the creation of an Advanced Manufacturing Research Centre for the successful development of new technology, indicating that the companies involved must have a common language of business model, a similar corporate culture, and a proximity between the user and the producer [10,11].

Some other authors suggested that there is a correlation between organizational culture and the implementation of advanced manufacturing technology [12]. The benefits of advanced manufacturing and its results are closely related to the cultural characteristics of the companies involved (operational benefits, organizational satisfaction, and competitiveness) [13]. Research was carried out regarding how the socio-political regions affect the results obtained from the technology acquisition and the separation between the technology producers and the place where technological processes are made [14].

The aim of this paper is to perform an analysis of the current state of the technology transfer network and fulfil a benchmarking of reference models to identify and then study the key processes (stakeholder management, communication plan, risk management, and funding) leading to the success or failure of an AMARC. The results of this study will define the characteristics of the AMARC as a compendium of the work performed and adapted to the application object environment. To do so, a four-step context analysis should be performed. First, we show the Basque aerospace sector, studying the work done by the cluster, Hegan (Basque aerospace cluster). Second, it is necessary to understand the manufacturing technology concepts in the aerospace sector that will help to focus the lens and to bring together projects in the AMARC. Third, it is mandatory to analyse the current status of the network in the Basque technology agents and, finally, examine the levels of technology acquisition with an approach based on NASA's index Technology Readiness Level (TRL), when a technology is considered mature and capable of being industrialized.

2. Background

2.1. The Basque Country Aerospace Sector

The aerospace industry is prone to large, international consortia for research, product development, production, and operation due to the system complexity, high reliability demand, multi-domain characteristic, extremely long life cycles, valuable products, scale effects, and others [15]. According to the studies done by Hegan, the Basque aerospace cluster sector—leaving aside the airlines, ground handling, and airport service organizations—includes companies that are focused on engineering, manufacturing, and design that integrate the work of first level (Tier 1), e.g., large structures, engines, and complete subsystems; companies that carry out the integration of second level subsets (Tier 2), e.g., components, tool manufacturing, machining, heat and surface treatment; and research companies; institutes; and universities. In 2017, these companies' aggregate turnover and employment are 2425 M € and 14,457 people, which represents 17.8% of the Spanish turnover and 25.5% of the Spanish aerospace employment. Moreover, the R&D investment done by these companies represents 15.9% of the Spanish total (201 M €) [16]. Like any other sector, the challenges are struggling to maintain competitiveness, to improve effectiveness, and efficiency and to maintain their advantages in a sustainable way. The cluster has also set as one of its priority objectives the internationalization of its companies through a strong R&D investment necessary to maintain their position in the market [17].

There are also some inherent risks in the industry that can be summarized as the volatility of the geopolitical environment, managing the supply chain, competition in domestic and international markets, managing and retaining the talent [18], to name a few. The best way to carry on those risks is through establishing collaboration strategies that generate future innovation opportunities linked to expected incremental updates in order to improve product quality and productivity (better), reduce product costs (cheaper), and respond to market demands (faster). For the aerospace industry, these opportunities include improving the safety and environmental impact of aircraft [2]. Industry professionals and researchers have developed a key interest in how advanced manufacturing technologies can be used as a competitive tool in the global economy to combat the phenomenon of market fragmentation, product life cycle reduction, and increased demand for customization [19].

2.2. Manufacturing Technologies in Aerospace

"Advanced manufacturing technologies (AMT) involve manufacturing operations that create high-tech products using innovative techniques and new processes and technologies" [20]. This definition refers to the manufacture of high-technology products, processes, and solutions for future manufacturing and services. Many of these technologies are transverse, but the facilities to carry out these processes are not. There is also a wide variety of technologies but, in the case of the Basque market, they are focused on two large blocks aero-structures and motor-engines. The selection criteria of key technologies and technological strategies is one of the foundations of the successful creation of the AMARC. Figure 2 shows the relation between technological level and market impact.

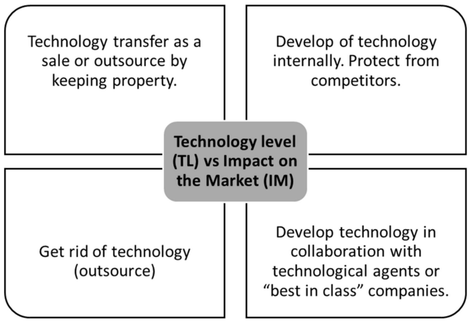


Figure 2. Technology level (TL) vs. impact on the market (IM).

AMARC activities should cover technologies that have greater impact on the market or higher technological competence. Furthermore, the results suggest that the company's technology strategy supports the development of both the network and technological skills [21]. The main objective should be the technological improvement and, therefore, the possible synergies between companies that participate in it.

2.3. Actual Situation of the Technology Agents' Network in the Basque Country

The technology agents' network in the Basque Country has some strengths in regard to applied research, such as:

- Network technology pioneer and leader state wide with high research capacity, driven by the history and importance of the industrial sector in the Basque Country.
- Solid public and private universities with a special relevance in engineering and sciences, basic pillars of manufacturing technologies. Faculty of Engineering of Bilbao is more than 100 years old.
- High levels of iterations with agents and European reference companies in the area of manufacturing, far above the rest of the country, through networking and collaborative projects.
- Clear support from Basque Country administrations, both in terms of investments and boosts to innovation forums and sectorial clusters, such as the Basque aerospace cluster.
- Strong iconic areas such as machine-tool manufacturing, capital goods, and automotive components and transportation, which have produced a strong pull.

However, some issues coming from industry demand for support remained unfilled. The same situation has been experienced in other countries with important academic tradition and large technology and industrial centres such as the UK, where there was a strong presence of technology centres with excellent capabilities, but that lacked a platform linking their developments and the industry needs. The lack was detected by the main Original Equipment Manufacturers (OEM) in the aeronautics world and by different government agencies, which prompted the creation of a centre covering these needs without duplicating what already exists in the field of basic or applied research. In the UK, the program was named Catapult.

2.4. Levels of Technology Acquisition

Introducing new technologies is an indicator of technological maturity in companies, and the Technology Readiness Level (TRL), designed by NASA in the late 1990s is a useful measure from an engineering/technical point of view (Table 1). The TRL index can be used as a rough estimation of the costs for conducting the required actions to reach the next TRL, time to market, risks taken, and uncertainty/lack of knowledge regarding the technology use/application and implications. While time-to-market shrinks with an increasing TRL, the costs within each step expand. A high TRL development within the aerospace sector demands large enterprises, workload, and infrastructure (for manufacturing and testing) and that cannot be achieved by universities.

Table 1. Technology acquisition process.

Technology Readiness Level	Transference Process	Agents
TRL 9—Complete industrialization TRL 8—Optimization TRL 7—Entry into production		Company
TRL 6—Application development in product TRL 5—Verification in production equipment	Technology transfer	AMARC
TRL 4—Verification in representative prototype TRL 3—Verification in the laboratory	Applied research	Technological Centres
TRL 2—Feasibility and profitability analysis TRL 1—Investigation of the fundamentals of technology	Basic research	Universities

AMARC—Advanced Manufacturing in Aeronautics Research Centre.

Two key factors shall also be considered: (a) The excellence at universities and technology centres to ensure a solid foundation of basic and applied research, and (b) an adequate transfer level between applied research and the results to industry, to avoid interference with the companies' production activity and to reduce the time and cost of transfer. TRL has been adapted by the manufacturing world as the MRL, in which M stands for manufacturing.

3. Methodology

A benchmarking based on a study of several documents and records can clear the path over how to assume a project of this nature, as well as the study of international references and the contextualization of this information to the Basque Country environment. In this case, it is composed of:

- Study of AMARC models created by aerospace companies in Europe and American countries that focus on the same technologies that has been identified as key for the Basque Country.
- Study of research focus of the AMARC identified before, their business models, and organizational plans.
- An analysis of technology, equipment capacities, and research capabilities, and a numerical evaluation of each characteristic according to this analysis (Table 2).

Table 2. Equipment capacity vs. research capacity.

Indicator	Description	Minimum	Maximum
CC	Scientific capacity: Scientific production in the last three years (doctoral theses, publications, patents, etc.) + staff size (doctors, researchers, etc.)	0	4
VR	Valuation of results: Direct or indirect assessment of results of collaborative projects or technology transfer in the last three years	0	6
CI = CC + VR	Research capacity: Global assessment of potential capacity and results	0	10
IE	Equipment suitability (for processes and tests): Technical quality of the equipment, similitude with industrial environment, suitability of process ranges, and useful working volume	0	6
DE	Availability of equipment: Term of response to requests for use and compliance with schedules	0	4
CE = IE + DE	Capacity of equipment: Overall assessment of suitability and availability	0	10

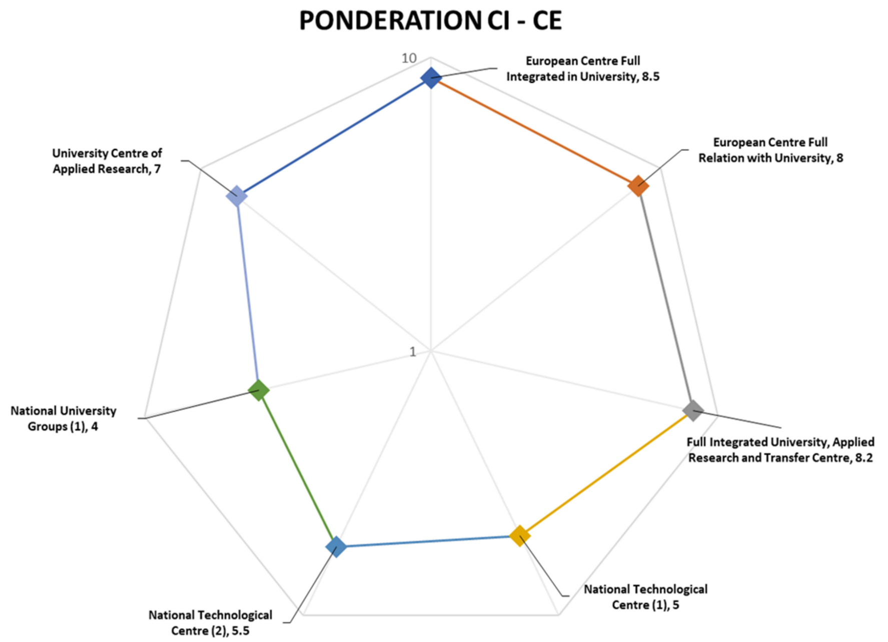
4. Results and Discussion

The public–private initiative can be key to the project's success, because the initial stages of a project of this type requires research, which means highly expensive and with a long time of specifications, where the commitment of public administrations can be an activating energy to projects of this type. The leverage effect of initial found can be obtained during the exploitation time of the AMARC.

Figure 3 shows the results of the evaluation based on the analysis of the recollected information to several centres in Europe with different configurations, carried out by the researchers. Here are compared (a) national university groups focused on applied research, (b) full integrated university groups focused on applied research with a relationship with companies based on specific projects, (c) national technological centres (without structural connection to the university), (d) university centres of applied research similar to the national university groups, but without the need to be financed by company contracts, and finally, (e) full integrated European centres, within the university (or very closely linked) with direct relation with the companies. Evidently each model depends on the national laws of the countries. However, in all the cases, those with more indexes involve universities in close ways, because university has a great advantage, bringing the training and young students together. Together with practical results regarding technology, key aspects such as industrial doctorate, training, lecturing in the last levels of degrees, and master science, connection of start-up entrepreneurship, etc. are the crux of the matter.

The benchmarking results indicate a similar position of the Basque technology agents, compared to the reference in Europe in areas such as advanced machining process, non-conventional processes, measuring techniques, simulation processes, systems integration, and process modelling in general for aircraft components. However, sometimes there is a dispersion of technological activity related to manufacturing and a redundancy of different agents investigating the same disciplines. The above causes are worsened by the lack of equipment and machinery with sufficient similarity to the industrial environment to provide the results in technology transfer projects. To reverse this situation, an investment effort is required. This is essential to develop a local network of excellence between technological agents and industrial companies (proper management of stakeholders).

As observed, there are several barriers related to transaction costs, coordination, management, and control of the activities of the various parties involved, which could inhibit the participation of companies in the investment share technology and R&D [22]. The main trend of innovation policies in the last two decades is characterized by what is called "cooperative paradigm", or the promotion of co-operation between sectors—industry, government, and research—and between rival or vertically related companies [23]. Therefore, proper management of the information transmitted to potential partners during the creation of an AMARC is fundamental. Taking into account the impact of co-operation in private and social benefits, the biggest challenge for public policy is to find mechanisms that promote co-operation [24].



TYPE OF CENTRE	CC	VR	CI	IE	DE	CE
European Centre Full Integrated in University	3	5.5	**8.5**	5	3.5	**8.5**
European Centre Full Relation with University	3	5	**8**	5	3	**8**
Full Integrated University, Applied Research and Transfer Centre	3.5	4.7	**8.2**	5	3.2	**8.2**
National Technological Centre (1)	2	3	**5**	3	3	**6**
National Technological Centre (2)	2.5	3	**5.5**	3	2.5	**5.5**
National University Groups (1)	2	2	**4**	2	2	**4**
University Centre of Applied Research	4	3	**7**	4.5	2.5	**7**

Figure 3. Results of the evaluation of CI (Research Capacity) and CE (Capacity of Equipment). Graph and data table.

Based on the collected information, it shall be considered that a cooperative model, in which several companies with common interests share risks and with the support of the supply chain, is the most appropriate and most likely to succeed management strategy of the AMARC project in the Basque Country. Consequently, the facilities must support the key technologies identified for the AMARC, advanced machining aerostructures, advanced processes for welding, and advanced machining aeroengines; facilities in which the industrial demonstration, launching, and acceleration of the initial production of new products can be successfully carried out. Furthermore, the reengineering process of existing products, the development of alternative manufacturing processes with the purpose of introducing qualitative leaps in profitability and the demonstration of the applicability of the developments of horizontal technologies shall be considered.

A proper risk management and planning must be conducted. Several studies have focused on evaluating the effectiveness and risks of R&D [25–27] and its influence on private efforts [28,29]. However, few studies have examined the criteria used by government assessors to assess these risks and projects [30,31]. It can be concluded that a centre with the aim of working around TRL 5–7 and involving public administrations, companies, and universities can help to increase the impact of applied research on final production lines, improving the general situation of the starting technological agent with respect to its former position in the international scenario.

5. Application to the Basque Country Scenario—Establishment of the Advanced Manufacturing Centre for Aeronautics (CFAA, in Spanish)

The new centre, CFAA, was inaugurated in 2017 in the Technological Park of Biscay, where several companies of the aeronautical and research sectors are located. The conception of this centre is a conjunction of initial ideas from the Basque Government (Dept. of Economic development and infrastructures), the University of the Basque Country (UPV/EHU) and the partnership for the Development of Advanced Aeronautics Manufacturing Techniques companies (more than 70 in 2019). The Basque Country Government and Provincial Council of Bizkaia were initial promoters and support the original idea, in collaboration with the Technological and Scientific Park of Bizkaia. CFAA enables the development and result transferring of research projects to production, without forgetting the generation, use, and fine-tuning of new knowledge in advanced manufacturing techniques [32]. Nowadays, the CFAA is formed by 78 partners, which has allowed to it complete several projects in different vital areas for the partners, and university. Twenty-five people form the staff of researchers, eight of whom are completing their PhD and seven, who are responsible for the project's coordination and research. It also has eight professors from the University who share their time in the centre's research. There are also 20 people from partner companies working in the centre and seven more are in dual training for partner companies. The combined nature of the technicians in the centre is one of the big strengths of the model.

In Table 3, the total number of companies in the partnership of companies is classified into type and sector. Types A, B, C have acquired a joint commitment to contribute to the centre through projects. Type D contributes in kind, giving tools or services to be used in the projects. As shown, several company sizes and sectors are involved, this is key because big companies have stronger R&D means and culture than SMEs that can be shared trough the proper ways.

Table 3. Centre for Aeronautics (CFAA) partners summary (2019), classification by role and sector.

Type	Industry	Quantity
A	Large-size machine tools	1
	Tier 1 aeroengines	1
B	Cutting-tool medium-size companies	3
	Machine-tools medium-size companies	1
	Metrology companies	2
	Metrology and additive manufacturing	1
	Machine-tool small-size manufacturers	1
C	Additive m.—machine developers	1
	Cutting tools and accessories	1
	Digital transformation	1
	Engineering services	1
	Tier 2 aeroengines	2
	University	1
	Welding equipment and consumables	2
	Work holding	2

Table 3. *Cont.*

Type	Industry	Quantity
D	Additive manufacturing—services	1
	Cutting tools and accessories	31
	Digital transformation	5
	Engineering services	4
	Technology providers	1
	Work holding and fixtures	5
	Digital transformation	1
	Engineering services	4
	Industrial clusters: (a) Machine tools and (b) aeronautics	2
	Metrology equipment	1

5.1. Daily Life Control—Project Time and Scheduling of Activities

The activity of the CFAA is centred on the planning and realization of projects included in a List Of Projects (LOP), in which the intensive use of the resources is sought in fulfilment of the aims of the centre. This LOP is prepared on the basis of the proposals made by each of the members of the centre, sent for study and acceptance during a period of the year by a technical committee. The duration of the project depends on the planning agreed between the partner project lead and the centre, taking into account the availability of its resources, which is established according to the order of arrival of the requests, followed by the hierarchy of the partners. In general terms, three to six months is the project time, because longer projects usually tend to lose some practical view; as a matter of fact, longer projects are divided into shorter activities to be able to give companies tangible results. Figure 4 shows how many projects are proposed and led by the type of partners, Tier 1 or Tier 2 aeronautical companies are those pulling the rope; however, machine tool manufacturers are very active as well.

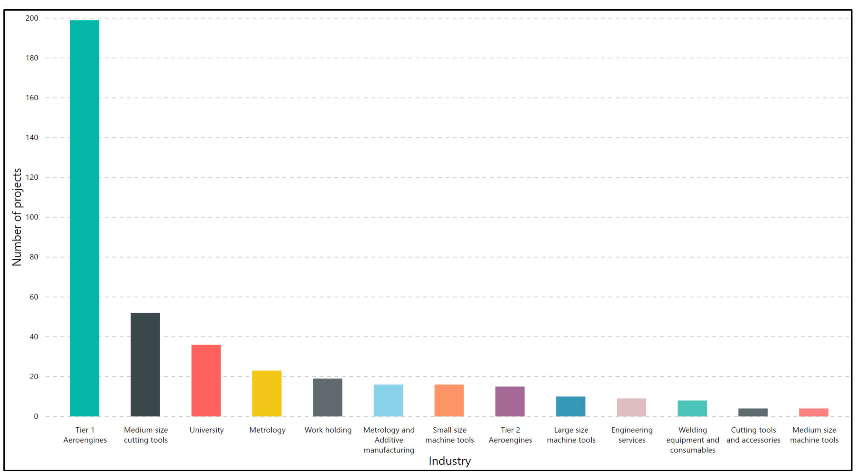


Figure 4. Project quantity resume by leader partner.

5.2. Sharing of Costs

As previously mentioned, the CFAA is the result of the support of several members. From that moment on, the financing of the activities and the acquisition of new resources has a mixed character. Initial funds provide by institutions were key to start the idea, and they had a real leverage effect on all launching activities in the foundation of the centre.

The year-based budget of the CFAA will come from the payment income of the amounts for the realization of projects under the charge of the companies that make up the centre; the income of R&D projects in collaboration between the University of The Basque Country and company-partners, and several sporadic collaborations outside the company partnership, non-collaborative projects developed by the UPV/EHU through the CFAA; projects and additional contracts demanded by companies that make up the group (and those that do not); training activities and technical assistance carried out by the staff of the centre; other services that may arise from the operation of the centre (analysis services, rental of space for activities, reports elaborated by the CFAA, and so on); and the income arising from other donations, subsidies, or contributions to the CFAA.

5.3. Property of Results and Data Gathering

Due to the collaborative nature of the centre, different non-disclosure and confidentiality agreements have been established for the activities of the CFAA, as well as their projects and results. Therefore, the ownership of property and the exploitation rights over them will correspond to the partner (or partners) that have financed the respective activity or the research project (either a company of the partnership or the own UPV/EHU for its own activities or for other works or projects in collaboration). However, those results that could disqualify, due to their publication or diffusion, the recognition of Industrial or Intellectual Property rights should be considered as reserved matters and not diffusible, unless an agreement to do so is reached between the parties.

On the one hand, the CFAA must preserve the confidentiality of all information received from the companies, which complies with the general agreement of confidentiality that involves the staff of the CFAA or assigned to it. The information provided by each company belongs per se to the company of origin, namely blueprints or significant technical details of parts and components. All personnel present regularly in the CFAA must register and sign the Non-Disclosure Agreement (NDA), which links the centre and the partners if they so demand.

The network established around CFAA also allows a rapid use of new results in daily production, and in some cases has made easier to exploit new patents, as in the case of cryogenic cooling using CO_2 (REF W02017/202622 A1). Anyway, some results are industrial secrets, to be use in daily production, so special care about information, pictures, and other issues must be kept in mind always.

5.4. Manufacturing Execution System (MES) at CFAA

The need to control the intensive use of the CFAA resources and respect the public–private nature of the information has established different tools developed by the centre, tending to create an "ad hoc" Manufacturing Executing System (MES) that allows acquisition data of the use of machines, record work time of staff, quality control, and finite programming of these resources, with the aim of making the audit of this information transparent, and on this basis, create not only horizontal, but also vertical control cycles. The data obtained from the different components of the system allows in turn to apply artificial intelligence techniques that facilitate the programming of the projects' tasks, the realization of the maintenance on the resources, and the creation of added value throughout the projects.

Graphical utilities were developed to manage the flow of projects and to define the load per machine, in addition to charge the costs per machine or technicians to each company account. As an example, Figure 5 shows the total number of hours invested by each group of resources in the development of the projects of CFAA from 2017 to 2019.

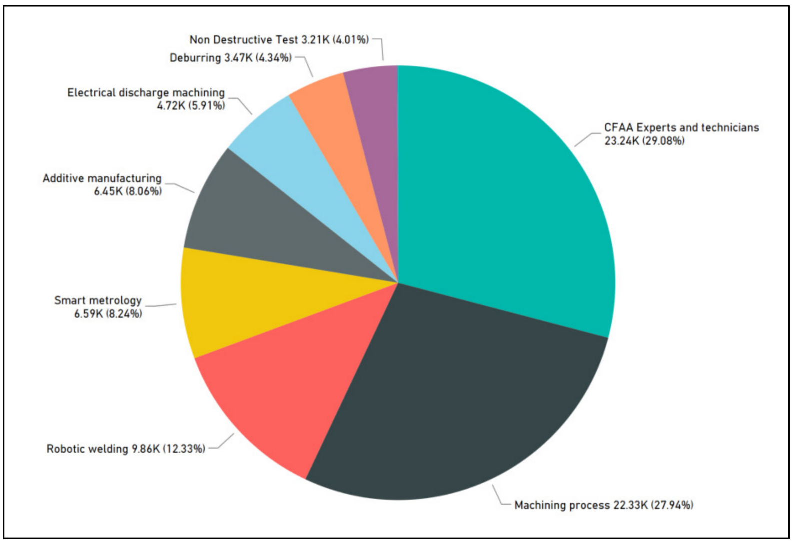


Figure 5. Executed hours and percentage of used resources in project execution 2017–2019.

5.5. The Effect of the Location at a Technological Park

The research type facilities of AMARC are welcome at technological parks because they are based on the presence of knowledge-based companies. For instance, around the University of Sheffield Advanced Manufacturing Research Centre (AMRC) a whole technological park has spread.

The Technological park of Bizkaia is one of the outstanding ones in Europe, close to the airport and surrounded by several companies which are partners of the CFAA. Taking advantage of the park's existence, the new centre was located here, with a high-tech surrounding in accordance with the aim of the centre.

Location is important in centres open to full collaborations. University faculties, vocational training schools, access by public transport are also important reason for the success of centres of this type.

5.6. Sustainability

Sustainability was undertaken in two lines, economic and environmentally. The economic performance of a centre of this sort must achieve the balance of incomes vs. costs in less than two years, taking into consideration that it is a non-profit research centre. Three scenarios can be presented, regarding budget evolution and term:

- Initial period. When costs can be slightly higher than incomes from companies' projects or by competitive calls. New models and systems always need some time to achieve their regular performance. The excess of incomes can equilibrate the initial shortfall during the following years.
- Budget balance. In the mid-term, balance must be achieved. The size of the AMARC must be escalated to this basic principle.
- Increase of incomes coming from projects. All money in excess of costs would be used for more people in the system, new doctoral grants, or new equipment. As an example, CFAA has increase a 21% in the three years since its inauguration.

Regarding environmental issues, a centre of this type does not make real production, however it must be an example of good practices. International Organization for Standardization (ISO) 14001:15 sets out the parameter for an environmental management system; it can be a global goal to achieve by the organization.

Technology can help to reduce the manufacturing impact, that is why, at CFAA, a technique under research is cryogenic cooling using CO_2 (second use of CO_2). This technology reduces machining temperature and can eliminate emulsion coolants (water + 5–10% oil) in the same applications [33,34].

In Figure 6, some environmental good practices are shown, performed at CFAA. To the left, a container for oil disposal and stained paper, a chip removal system and a conveyor, metal powder for additive manufacturing, with particle size ranging from 10 to 20 micrometres. Last image is a detail of how powder is treated before being used. The CFAA waste and disposal system is around 7–11% of a real factory of the same layout and machines but at full production.

Figure 6. Harmful substance deposit, chip collecting system, metallic powder for additive manufacturing, and powder testing.

6. Conclusions

It can be concluded that in cases and industrial sector with structural deficit of certain knowledge and skills, an advanced manufacturing research centre could be a good solution. The aerospace sector, as a whole, is an intensive investment sector in R&D and some others in the supply chain as well, as is the machine tool sector. However, most SMEs in the Basque Country do not have R&D fixed structures for developing their own research activities. Important efforts are being made in upgrading student's qualifications through the specialization and improvement of the local universities and formation centres. They are also collaborating with the local companies to know the main flaws of the graduates. Moreover, there is an important network of technology centres in the Basque Country with the ability to work in the aerospace sector.

The ultimate goal of the AMARC concept should not be focused on centres dedicated to horizontal development of specific manufacturing technologies (machining or welding technologies), but on those dedicated to the totality of the manufacturing process, integrating development activities of pure process modelling tools, simulation, adaptive control flow of operations, automation, reaching a maturity level that allows the technology flow without risk of the developed productive portfolio of partner companies.

Industrial partners could assume technology acquisition activities with a high probability of success. The sharing of funding, both public and private, can improve the profit margin and the capacity of research and development with other partners, which would increase the chances of success. The critical mass created will allow participation in consortia in European or national projects under conditions of greater equality with the European centres of reference, and with the possibility of choosing to participate in activities with higher technological return and access to larger budgets. Small companies participating in centre would make an even greater leap, considering their investment limitations in R&D and the difficulty for developing steady technology acquisition activities.

Machine-tool systems and tool manufacturers have better opportunities to sell their products to companies if development projects were successful previously at the AMARC, to gain access to better funding, to improve their proximity to end customers and to obtain benefits from access to technological excellence inside and outside the AMARC. This type of centre is also a showroom for machine tool assemblers and other technology providers.

After presenting the premises and antecedent, several conclusions can be pointed out:

- Research centres around TRLs 5–7 must comprise several companies, universities, and strong support from public administrations.
- Collaboration of the supply chain with OEM or Tier 1 is highly recommend, having the new centre model as a vertical conception: Effort is focused on one particular industrial sector.
- The centre can boost the relative position of one research group in a university with applied research to leading positions.
- The initial list of machines and systems is key to achieve an intensive use of the centre means. Machines must be purchased considering a useful life of at least seven years.
- The location in a technological park with common services is a key aspect in the project. Common services, environment, and easy access by public transport is key.
- Management of the centre must be performed by a university or technological agent, all thinking in being an open centre to all partners and that the management of the centre is really on behalf of the full consortium.

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Conflicts of Interest: The authors declare no conflicts of interest.

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8

Project Management Metrics.

Having analysed the first two components, UIC, its characteristics and common collaboration strategies, and the necessary TRL and best practices to be able to transfer research results to the industry in a fast and effective way, it was necessary to develop research related to the different metrics for measuring R&D project effectiveness.

Due to the inherent uncertainty regarding the realisation of R&D projects, project metrics and their organisations were studied from two different perspectives. First, at the project level, assessing project success during the project life cycle and subsequently analysing what it means for an organisation and its stakeholders, intending to find standard success criteria for measuring project success. Secondly, at the organisational level, an exercise was carried out to identify Key Performance Indicators through a lean approach, which sought to identify the primary metrics for measuring the effectiveness of project-based organisations.

The results of this research are summarised in the publications shown below.

8.1 CP. 3 - Conference Paper.

Farokhad, M. R., Otegi-Olaso, J. R., Pinilla, L. S., Gandarias, N. T., & de Lacalle, L. N. L. (2019, September). Assessing the success of R&D projects and innovation projects through project management life cycle. In 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS) (Vol. 2, pp. 1104-1110). IEEE [8].

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The 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications
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Assessing the Success of R&D Projects and Innovation Projects through Project Management Life Cycle

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***Abstract*—The success of R&D projects and innovation projects have a significant effect on technology enhancement and new product development, while developing project success criteria and customizing methods to measure the project success for R&D projects and innovation projects is a demanding task. In addition, the late assessment of project success in R&D projects and innovation projects has been associated with noticeable waste in time and budget.**

This research is based on previous studies of the authors that customized the new hybrid methodology to manage R&D&I projects in CFAA and validated the project success dimensions and criteria. In the previous researches of authors the hybrid project management methodology for R&D&I projects was developed and the project success dimensions and criteria were defined.

This research aimed to answer the following question regarding the R&D&I project success evaluation. When is an appropriate time to assess the project success? Apparently the late assessment of project success is associated with significant drawbacks, therefore, the assessment of project success during the project management life cycle is the purpose of this research.

The research methodology is based on the survey regarding the assessment of the project success from the project manager's perspective. The project's success criteria in the survey were translated into qualitative questions ranked through Likert scale and the survey was constructed through reviewing the literature regarding the project success criteria.

The validity and reliability of survey were confirmed through smart PLS software to validate the relevancy of questions to measure the contribution of each project success dimensions in the project's success. Finally, the extension of the Hybrid R&D&I project management methodology is proposed which contains the gates to assess the project success criteria by means of this survey in each gate during the project management life cycle.

Keywords—Project's success criteria; Hybrid project management methodology; R&D projects; innovation projects

I. INTRODUCTION

The significant growth of interest in the globalization of industrial activities and market economy has let to great concern about the improvement of research and development projects as well as innovation projects, therefore remarkable attempts have been done in labs simultaneously in the market place to develop R&D projects and innovation projects, so that the success of the R&D projects and innovation projects were associated with obtaining significant competitive advantageous for companies. CFAA is an advanced manufacturing center, which implement plenty of R&D projects, innovation projects as well as R&D&I projects in aeronautic propulsion system sectors and cooperate with several partners in aeronautic field and Basque university to accelerate technological improvements in this field.

In fact, R&D&I projects are R&D projects which are simultaneously innovation projects .The success of the projects in CFAA has a significant effect on the improvement of aeronautical technology and knowledge generation since the main mission of this center is to generate knowledge, new methods and technology for their partners in aeronautic propulsion system sectors ;in addition CFAA organizational objective is to apply the newest knowledge and technology achieved during the projects to increase the future opportunities of this center. Its worth's noting that, in this center the lack of research about evaluation of project success is obvious and there are plenty of completed and ongoing projects which their success rate has not assessed.

As a result, the authors aim to assess the R&D&I project success during the project management life cycle. In order to assess the project success, Section 2 refers to the characteristic of R&D project and innovation projects and in section two, the previous investigations of the authors to customize a hybrid project management methodology for this center is summarized. It is followed by identification of project success dimensions and project success criteria which is a part of another investigation of the authors and represented in the third section. It is followed by introducing the new extension of project management methodology to assess the project success and finally the research methodology and results are proposed.

A. Section 1 – R&D Projects and Innovation Projects Characteristics

To manage the projects in CFAA, it is essential to understand what type of projects is implemented there. Reviewing the existing information and interviewing with the project coordinators and professionals in CFAA have led to the classification of projects in this center. Table I represents this classification.

TABLE I. CLASIFICATION OF PROJECTS - CFAA

Type of projects	Percentage
Creation or development of new product technology platform	8.31%
Innovation	3.99%
Product or technology enhancement	46.84%
Project oriented to new product or process	40.86%

Considering the classification of the projects, apparently, they are innovative projects as well as R&D projects which in some cases, they are R&D and innovation projects called R&D&I projects.

From one side, managing R&D projects are demanding task since they are complex projects with high level of uncertainty and high risks, including highly intelligent activities, which are associated with barriers, dramatic collaboration changes, breakthroughs and the quality is judged by experts [1].

From the other side, in R&D projects, the goal is "ambitious" and "challenging so that Stuckenbruck [2] emphasized on renewing the planning and idea. Since R&D projects don't have defined goals and process therefore in initiation phases detailed planning is not possible, then the managing and assessment of success in such projects is a not easy task. Mikulskiene [1] mentioned that there are a lot of issues in managing R&D projects related to planning, resource allocation and scheduling since R&D project should have flexible planning to cope with new methods and changes.

Furthermore, in CFAA there are innovation projects, which in turn have the non-linear process [3] and managing them are associated with remarkable challenges such as the possibility of failure, the high rate of ending up projects without any results, the variable project scope, the long-lasting project life cycle, the conflict between researchers' interest and companies' interest, difficulty of bounding innovation projects to defined time periods and planning, and not-fixed scope of innovation projects which is changing due to internal and external factors [4].

Taking into consideration the identity of R&D projects and innovation projects as projects with ambiguous goal and method and aggressive scope, customized project management methodology and project success criteria are needed to manage them.

II. HYBRID PROJECT MANAGEMENT METHODOLOGY FOR R&D, INNOVATION AND R&D&I PROJECTS IN CFAA

The previous investigations of researchers regarding customizing the hybrid project management methodologies for R&D&I projects in CFAA have resulted in a new hybrid project management methodology, which is a combination of stage-gate approach with agile approaches. Obviously, this methodology has divided the projects into manageable and controllable phases according to the type of activities in CFAA, besides this methodology is associated with several positive characteristics which are elaborated below.

- The defined phases guarantee the control of outputs before transferring to the next phase.
- The iterations and spirals provide the chance for flexibility, learning and responding to the flexible environment.
- Overlapping stages increase the possibility to have parallel activities.
- Non-linear structure with backwards steps for modification and editing the ideas and methods.
- Application of Scrumban board as a communication tool to illustrate the status of the activities (to be done, in progress, done, blocked and discarded).
- Stand-up meeting to accelerate the problem solving and collaboration regarding the blocked, discarded activities or work in progress.
- Research phase to define the scope-baseline [5]. Table II represents this approach in details.

TABLE II. HYBRID PROJECT MANAGEMENT METHDOLOGY

Stage No	Name	Input	Output	Characteristics
1	Initiation phase	Project document and requirement, organizational process assets and external environmental factors	Project charter, primary planning	Expert meeting
2	Research	Project charter, Primary planning, Project's goals	Feasibility study results Scope baseline	Spirals and iterations, Scrum-board stand-up meeting
3	Planning and detailed design	Feasibility study results Scope baseline	Cost baseline, time baseline, detailed planning and scheduling, prototype and design	Spirals and iterations, Scrum-board stand-up meeting
4	Implementation	Detailed planning and scheduling	Deliverables	Spirals and iterations, Scrum-board stand-up meeting

5	Test	Deliverables, Task performance reports	Validated deliverables, change request	Spirals and iterations, Scrum-board stand-up meeting
6	Release	Validated deliverables, change request	Project documentation, Data and information, New technology, knowledge or technology enhancement	Reporting Expert meeting

III. PROJECT SUCCESS DIMENTIONS IN CFAA

The success of projects is a commonly investigated topic through different researches, however, there is no consensus on its definition [6].The traditional project management approach emphasized on controlling iron triangle through the projects life cycle, while obviously there are a significant number of successful projects which exceed the time ,cost and other constrains . In order to assess the project success Cooke-Davies [7] emphasized on customizing the project success criteria to measure the project success, since there are a lot of project success criteria and managing and evaluating all the projects' success criteria simultaneously is challenging and impractical [8]. Managing R&D&I projects are challenging task and the possibility of failure and ending up projects without any results is remarkably high due to the characteristics of the R&D &I projects as projects with not defined methods and goals. In fact, not only the characteristics of R&D&I projects had effect on managing and evaluation of project's success, but also the mission of CFAA , organizational objectives and policies had effect on assessing the project success, therefore, to define the customized R&D&I project success criteria for CFAA, researchers in their previous research tried to categorize the factors which contribute to project success into several dimensions and define the customized criteria to measure the success from each dimension.

The previous attempts of the authors to assess the R&D&I project's success from a project manager's perspective through literature review and expert judgment meeting have resulted in the identification of four dimensions, namely future potential of the projects, project management factors, mission and objective of the center and partner satisfaction. In order to assess the contribution of each dimension to the project's success, the project's success criteria were established according to the previous researches of Ramezani et al. [9]. The four dimensions and related criteria are elaborated below:

- Future potential of the projects: success criteria defined as the level of innovation and creativity, generating a new product line or new technological capability, increasing the organization reputation and future opportunities derived from this project [6], [10], [11], [12], [13].
- Project management factors: success criteria such as time, cost, quality and scope [10], [18], [14].
- Mission and objective of the center: according to the CFAA mission, the number of scientific publications, achieving the project's objectives are defined as success criteria [10], [7], [15].
- Partner satisfaction: Written or verbal feed backs about the use ability , user friendly aspects of deliverables and meeting the partner's expectation are considered as success criteria [11] [16].

IV. ASSESSING THE PROJECT SUCCESS THROUGH PROJECT MANAGEMENT LIFE CYCLE

In order to assess the project success during the project management life cycle, the CFAA methodology, which was the combination of stage-gate approach and agile approaches is to be extended by adding the gates after each phases, in fact, each gate has its own project success criteria to control and assess the project success through controlling and evaluation of the outputs by means of defined criteria. The Fig. 1 represents the extension of the R&D&I project management methodology.

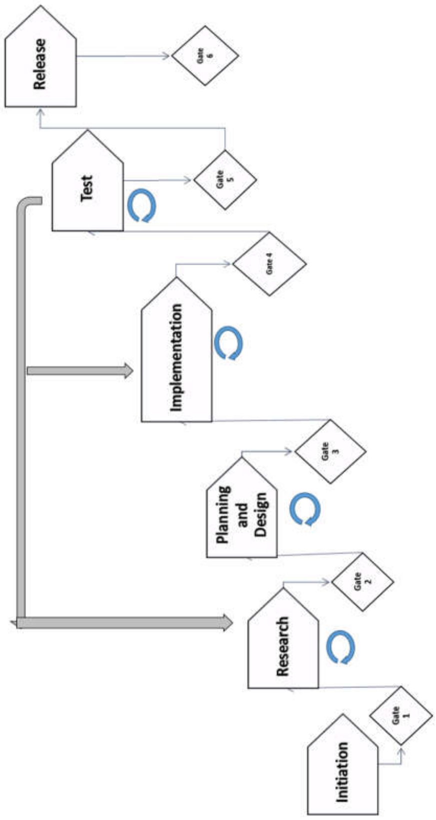

Figure 1. Extension of R&D&I Hybrid Project Management Methodology

Surprisingly, some of the criteria should be evaluated in several gates to ensure the accuracy of the evaluation, while some phases do not have any criteria. Table III shows each gates and success criteria which should be measured.

TABLE III. R&D&I PROJECT MANAGEMENT METHODOLOGY

Phase	Gate No	Out put	Success Dimension	Success criteria
Innitiation	1	Project charter Primary planning		
Research	2	Feasibility study results, Scope baseline	Project management factors Future potential	Scope Innovation Capability enhancement
Planning and design	3	Cost baseline, time baseline, detailed planning and scheduling, prototype and design	Partner satisfaction	Meet partner expectation
Implementation	4	Deliverables	Project management factors	Time Cost Resources
Test	5	Validated deliverables, change request	Project management factors Partner satisfaction	Quality Useability User friendly Scope
Release	6	Project documentation, Data and information , New technology , knowledge or technology enhancement	Future potential Partner satisafction Mission and objective Project management factors	Future opportunities Innovation Reputation Capability enhancement User-friendly Scope Time Budget Meet partner expectation Useability limitation knowledge generation Tacit knowledge Achieve project objective Experience generation

V. METHODOLOGY

The research is based on a survey which is constructed through reviewing different literature about assessing project success and the authors tried to correspond the R&D&I project success criteria introduced in 4 project success dimensions for CFAA as the survey questions. To assess the project success, each criterion was translated in the form of questions with qualitative responses rated through Likert scale from 1 to 5. The survey is attached in Table IV.

TABLE IV. RESEARCH SURVEY

Project Success Dimension	References	Project Success Criteria	Project success question
Project Management Factors	[23]	Scope	Completed according to specification
		Quality	Met planned quality standard
		Resources	Resources mobilized and used as planned
		Time	Finished on time
		Cost	Finished within Budget
Future Potential of The Projects	[23], [11]	Future Opportunities	Enabling of other project work in future
		Reputation	Project has good reputation
		Innovation	Innovation and creativity of the deliverables
		Capability Enhancement	Generating a new product line or new technological capability
Partner's Satisfaction	[16], [23]	Usability	The usability of project's deliverables satisfies the needs of end-users or partners
		Meet Expectation	Achieving the Written or verbal appreciation, positive feedbacks or recommendation expressed by partners.
		Defect and Limitations	The number of the claims, complains and negative feedbacks from partners or even penalties.
		User Friendly	The project's products are easy to use for end-users
Mission and Organizational Objective	[24], [23]	Explicit Knowledge Generation	The number of scientific publications in peer-reviewed journals were generated by this project
		Experience	The number of scientific publications in peer-reviewed journals were generated by this project
		Tacit Knowledge Generation	New understanding/knowledge gained
		Project's Objective	Project achieved its purpose

The smart PlS software is selected since this software is based on partial least squares method, in which the small sample of data is used [20].The population of the research was 120 R&D projects and innovation projects and the simple random sampling method was used to choose the sample of the population. Considering the Cochran formula, the sample size was about 91 projects and the researchers received 90 valid responses from the project managers.

$$n = \frac{Nz^2pq}{Nd^2 + z^2pq}$$

N = 120
p, q = 0.5
D = 0.05, Z = 1.96

In order to test the reliability of the survey in Smart Plus software, the tow criteria of Cronbachs Alpha and Composite reliability are applied [19]. The validity of the survey, which contains the project success criteria in the form of question was validated through two separate phases. First phase the expert meeting with professionals and project managers in CFAA was held to ensure that the questionnaire has the ability to measure the intended purpose and second phase [22].

The validity of the survey in Smart Plus software was confirmed through Confirmatory factor analysis. In this method, the factor load illustrates the relationship between the questions with the latent variables, and the acceptable amount of the factor load is greater than 0.4; in the case that factor load is less than 0.4 the question is irrelevant and should be omitted from the model [19].

To evaluate the success of projects, it is essential to define how much each criteria from the project managers' point of view is important; therefore the expert meeting with project managers resulted in defining the importance weight for each criterion, which is represented in Table V. As a result, the below formula is suggested to assess the project success.

PS = Project success
Wi = The importance weight
Ci = Criteria rank (1-5)
PS = ∑ (Wi/5) *(Ci)

TABLE V. DEFINITION HOW MUCH EACH CRITERIA FROM THE PROJECT MANAGERS' POINT OF VIEW IS IMPORTANT

Dimensions	Questions	Rate AVE
Project management success factors	Completed according to the project specification	0.04823
	Met planned quality standard	0.04823
	Resources mobilized and used as planned	0.04823
	Finished on time	0.04823
	Finished within budget	0.04823
Future Potential	Enabling of other project work in future	0.067901
	Project has good reputation	0.067901
	Innovation and creativity of the deliverables	0.067901
	Generating a new product line or new technological capability	0.067901
Partner satisfaction	The project satisfies the needs of end-users or partners	0.059156
	Achieving the Written or verbal appreciation, positive feedbacks or recommendation expressed by partners	0.059156
	The number of the claims, complains and negative feedbacks from partners or even penalties	0.059156
	The level of correspondence with the partner expectations	0.059156
Project goals and mission (knowledge generation)	The number of scientific publications in peer-reviewed journals were generated by this project	0.062654
	Experience gained through this project	0.062654
	New understanding/knowledge gained	0.062654
	Project achieved its purpose	0.062654

VI. RESULTS

A. Reliability of survey

According to the methodology, the results of Cronbachs Alpha and Composite Reliability test are showed in Table VI. In the case that Cronbachs Alpha and Composite Reliability are more than 0.7 the questionnaire is reliable, while the Cronbachs Alpha and Composite Reliability less than 0.6 are not desirably reliable.

TABLE VI. QUESTIONNAIRE'S RELIABILITY

Project success dimension	Composite Reliability	Cronbachs Alpha
Future potential of the projects	0.886	0.828
Mission and organizational objective	0.861	0.789
Partner's satisfaction	0.772	0.726
Project management factor	0.876	0.822

As obviously all the variables have the Cronbachs Alpha and Composite Reliability more than 0.7, As the results, the questionnaire are reliable.

B. Validity of the survey

Considering the results of confirmatory factor in Table VII, which is illustrated ,reveals the fact that, the factor load for all questions are greater than 0.4, therefore; the structural validity is confirmed. In the other words the criteria are related to the project success dimension.

TABLE VII. CONFIRMATORY FACTOR ANALYSIS

Project success dimension	Project success questions	Load factor
Project management factors	Completed according to specification	0.41
	Met planned quality standard	0.41
	Resources mobilized and used as planned	0.42
	Finished on time	0.41
	Finished within Budget	0.58
Future potential of the projects	Enabling of other project work in future	0.52
	Project has good reputation	0.42
	Innovation and creativity of the deliverables	0.69
	Generating a new product line or new technological capability	0.44
Partner's satisfaction	The usability of project's deliverables satisfies the needs of end-users or partners	0.43
	Achieving the Written or verbal appreciation, positive feedbacks or recommendation expressed by partners.	0.48
	The number of the claims, complains and negative feedbacks from partners or even penalties.	0.50
	The project's products are easy to use for end-users	0.42
Mission and organizational objective	The number of scientific publications in peer-reviewed journals were generated by this project	0.46
	The number of scientific publications in peer-reviewed journals were generated by this project	0.66
	New understanding/knowledge gained	0.52
	Project achieved its purpose	0.51

C. Interpretation of the results of the survey

According to the results of the conformity factor analysis all the criteria are related to the project success dimension and the question can measure the intended criteria; besides the collected data through the survey were used to measure the R&D&I project success through the suggested average formula and results show that the average for project success is 77.16 and 8 projects have succeeded 100 percent, while the minimum success rate was 59%.

The Fig 2 shows the average contribution of project success dimension in the average project success in CFAA.

Obviously, partner satisfaction has the minimum contribution in the total project success, while the implemented projects in CFAA were significantly successful to create the potential of innovation and creativity in this center.

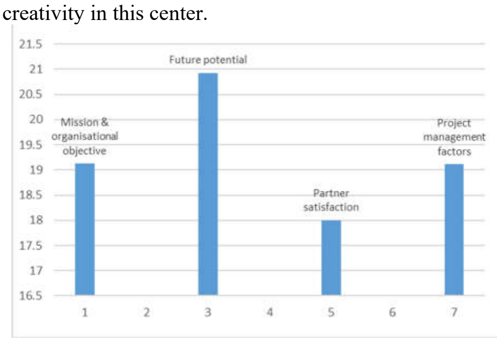

Figure 2. Project Success Dimensions

VII. CONCLUSIONS

Success of R&D&I projects has a significant impact on technological enhancement, while usually managing and controlling the R&D&I projects is not easy. In order to manage the R&D&I project and prevent from dramatic failures, this research investigated meaningful criteria for measuring success of the projects during project management life cycle. The results revealed the fact that CFAA has been successful in implementing the R&D projects and innovation projects and this center has th potential to enhance the new product lines and platforms for new technology, innovation and creativity in the future.

Furthermore, CFAA was approximately successful to implement the projects on time and within budget as well as creating the new knowledge and technology.

On the other hand, since the partner satisfaction had the lowest contribution of projects success; therefore, the customer-oriented strategies to increase the partner satisfaction is suggested.

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Project Success Criteria Evaluation for a Project-Based Organization and Its Stakeholders—A Q-Methodology Approach

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Abstract: The criteria that define project success change from one project to another, also from organization to organization, making success contextual for both the project organization and its stakeholders. This paper proposes a way to bridge this gap between what project success means to an organization and to its stakeholders in the context of Research and Development (R&D) projects. To achieve this, the available literature on project success has been analyzed to convert the different aspects identified into tangible units, allowing us to define and analyze the success criteria of a project in different dimensions. Subsequently, using Q-Methodology, which allowed us to determine among subjective opinions of Project Managers (PMs) of a project-based organization and their internal stakeholders, we will determine which criteria, within the previously identified dimensions, they consider as the most important for the success of a project, aiming to identify common success criteria that can be measured and controlled in the projects. Achieving the project goal, customer satisfaction regarding the quality of the activities, and knowledge generation turned out to be the most important criteria for PMs and stakeholders.

Keywords: project success; q-methodology; research and development projects; project management

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1. Introduction

Project management has different characteristics in the public and the private sector, not just due to a clear and on occasion opposite focus, but also practices, tools, resources, stakeholders, expertise, to name a few [1]. In companies, the incentives to bring a project to fruition are based on the measurable commercial results of the businesses, while for universities, it is the maximization of measurable results derived from research in the form of articles, theses, or patents [1].

Nevertheless, when collaboration between the two sectors is pursued, in the management of common Research and Development (R&D) projects carried out in intermediate Knowledge and Technology Transfer Organizations (KTTOs) close to the Technology Readiness Level (TRL) 5 to 7, a series of endemic problems tend to appear [2]. Sometimes, those problems result in a low success rate of the projects and waste of available resources for R&D in companies and at universities. However, these intermediate KTTOs are instruments far too fundamental and essential within the innovation process to be dismissed [3]. Therefore, new ways in which to manage, measure, and analyze before, during, and after these projects, but also to know the projects' success factors and to conduct them under these premises, are required [4].

KTTOs have proved to be a satisfactory means to enclose the public and private sector and in this way help local economies [5]. The Advanced Manufacturing Center for Aeronautics (CFAA, by its initials in Spanish) is a prominent example of the university–company model, which implements R&D projects and innovative projects to generate knowledge, new methods, and technology for their partners, mainly in aero-engine system sectors, which benefit from the priceless experience achieved throughout the development of more than 300 projects and more than 200 scientific contributions in the last 4 years [6], to increase the future opportunities of the CFAA and its partners [7]. In addition, working on TRL 5–7 [8] guarantees quick knowledge transfer, which promotes mutual benefits to companies and universities from a micro- up to a macro-economic point of view, so that universities obtain funding to conduct their research and to train their staff that enables them to respond positively to the demands of the labor market [9].

The success of the projects at the CFAA has a significant effect on future opportunities of the organization and the improvement of aeronautic technology in the region [10]. However, the lack of control, measurements, and research about evaluation of project success can be identified as an improvement opportunity in this Center.

It is worth mentioning that the success criteria by which the CFAA has been used up to now was that a project was considered successful if it could be delivered to the customer and the customer was satisfied with the outcome, mostly because the involvement of the project owner was high during the project development. This way of measuring project success can be improved, according to Munns and Bjeirmi [11], as the measurement of project success is only conducted at the end of the project life cycle, when project management outcomes are available and it is convenient to measure. It also goes hand in hand with Drucker's definition [12] mentioned as "Effectiveness" or "doing the right things". In the context of the definition, projects are not judged by their efficient use of resources but by the way in which the organization asks itself the question: "Does it work?". This, however, leaves out success criteria that are aimed at ensuring the sustainability of the system, making the best use of available resources, emphasizing the most important aspects for the stakeholder and for the organization [13].

However, a safeguard can be made in that the organization that owns the project is the one who must have previously studied the different success criteria of the project they are commanding. For example, if the technical improvement requested can be viable in their productive environment, or if the productive techniques used can be sustainable and applicable in environments other than the experimental one, or if the variables measured and that guarantee the success in the management of the project (thanks to the fulfillment of the objective) are valid, applicable, and expandable in their organizations. Naturally, the organization in charge of carrying out the project can help to determine the answer to some of the questions raised, however, the holistic experience is held by the project owner and not by the organization carrying out the project.

There are numerous ways to define project success, and each of these ways differs based on the kind and scope of the project [14,15]. Typically, project success is described as the fulfillment of some externally perceived criteria [16]. Criteria, however, refer to a rule or standard by which something is assessed [17]. Project success is traditionally assessed based on the three major criteria of the so-called "iron triangle": cost, time, and quality (or scope) [18]. Moreover, even though these ideas are distinct but related to one another, success factors and success criteria have been used synonymously in project management literature. The collection of circumstances and events that help a project to succeed are known as success factors [17], and success criteria are the successful outcomes of projects and are the parameters by which success is measured [19].

Although the desired benefits might be stated in the benefit-management plan and business case of a project, current standards do not define how success or failure criteria will be determined [20]. Without performance metrics for success, an organization cannot be effective since it is impossible to know whether the right things are being achieved. Even with initially defined success criteria, the question remains if a project can succeed in achieving goals that it was not intended to reach, since the pace of change increases and organizations encounter environments which are usually described by volatility, uncertainty, complexity, and ambiguity [21]. Even if the project goals are achieved at the end of the project, how can we measure the success of that project if we do not even agree on a definition of it in the context of project management [22–25]?

The criteria for defining project success change from one project to another, from organization to organization, and even within the same project, making success contextual to both the project organization and its stakeholders [26]. The identification and management of the project success criteria play a crucial role in achieving project success in organizations. Project managers (PMs) of the organization and internal stakeholders of the projects are active and crucial actors in identifying, evaluating, and contributing to improving project management practices in the organization.

According to research, stakeholders may have various ideas of what makes a project successful, both in terms of how important the criteria are and how the project's achievements compare to the criteria [27,28]. According to Davis [29], the perceptions of success by stakeholders are significant, as are the perceptions of important criteria and actual performance.

The need to control the project and the outcomes that are generated during the project life cycle is of vital importance to the organizations involved in the project. An approach is based not only on the success of the project management or on the fulfillment of time or cost constraints. It is necessary to analyze from the early stages of the project the quality of the work completed, and thus be able to analyze whether these results go hand in hand with the objectives not only of the project but also of the stakeholders. A more holistic understanding of project success can be achieved by measuring success throughout the project life cycle and including stakeholders in these measures of effectiveness [11,30].

We have been able to observe the relationship between the perception of project success for stakeholders and for PMs (or their organizations), and, despite some theoretical examples [29,31,32], there is still a need to explore what are the success criteria affecting both stakeholders and the organization in the development of public–private collaborative R&D projects in KTTOs. Therefore, the present research attempts to answer the following research questions (RQ):

- RQ1: What are the most important success criteria in public–private collaborative R&D projects, according to PMs and internal stakeholders?
- RQ2: What are the different subjective perspectives according to project managers and internal stakeholders?

This paper is organized as follows: we start with a literature review necessary for the description of the concepts and dimensions of project success criteria and their impact on the evaluation of a project and how they can affect the decision-making process of PMs. This is followed by a description of the research design. The results of the study are then described, and finally, the paper ends with a summary of the conclusions that can be drawn from the study.

2. Literature Review

Projects aim to deliver benefits in various ways to an organization. These desired benefits are usually formulated in the early stages of the project in association with a benefit-management plan that documents the performance reviews and evaluation of the success of the project [33]. Once the project objectives are established, strategies are defined and tactics are implemented to execute them in order to achieve the results and enable the organization to achieve the desired benefits defined and agreed upon for the project. The relationship between project success and different aspects of project management is being addressed in a growing number of studies. According to Web of Science, more than 220 research articles, proceeding papers, reviews, and book chapters have been published during the last 10 years demonstrating that, e.g., project success remains as a vibrant school of thought, as do the earlier definitions, measurement scales and dimensions, and assessment techniques that Pinto and his colleagues developed [34]. Mir and Pinnington [23] analyzed that project management performance is correlated to project success, and that KPIs and staff are the most influential aspects of project success. Joslin and Müller [35] have also found that there is a positive relationship between the project management methodology used in a project and project success, showing that access to a comprehensive project management methodology and the ability to know which of the elements can be applied to any given project represent almost 22.3% of the variation in project success. Nixon et al. [36] also found that the performance of the project leadership has been cited as a critical success factor determining the success or failure of a project. Finally, Carvalho and Rabechini [37] verified the significant and positive impact of project sustainability management on project success dimensions, among others.

2.1. Project Success

Project success as the heart of project management, and the factors that affect it, is a commonly discussed topic in research in project management and it is therefore among the top priorities of PMs and further stakeholders. The understanding of success has changed over the years, with different focus points, as depicted in Figure 1.

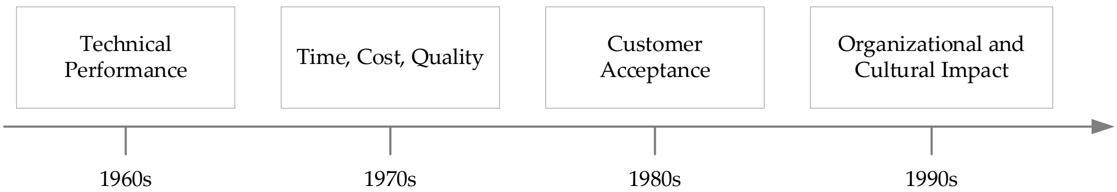

Figure 1. Historical Success Definitions, based on O'Brochta [20].

Success factors are defined as elements needed to be successful. They are independent variables that can be influenced to enable success. These elements include circumstances, facts, and influences [17,34]. Success factors should be identified and analyzed, if these are in place, or if actions can be undertaken, to enable and strengthen them to reach the level required to achieve success.

Due to the complexity and uncertainties which projects naturally face by their characteristics, it is difficult to stay within all given constraints and reach the initially desired targets. However, a "project can be a success even though it takes more time or [it] is more expensive than initially expected" [38,39]. To effectively measure success, success criteria must be defined upfront and reviewed and adapted continuously, since the environment can change, or new stakeholders may emerge, or even the point of view of a stakeholder can change unforeseeably with connected benefits, or simply to ensure justification [40]. If the company's environmental factors or organizational process assets are altered, success criteria can be revised through formal change-management processes or projects can be closed prematurely, which can also be considered a success, as no resources are wasted. Furthermore, the output of the evaluation of the successfulness of a project can differ from the point of view of the stakeholders. While a project might favor one stakeholder (internal or external), others can perceive the project to their disadvantage and are therefore dissatisfied based on different or even contrary perspectives, interests, and objectives [41]. The viewpoint, as seen, can be dependent on different backgrounds, such as cultures, industry, organization, nationality, gender, or personality.

Another element that makes the success criteria of a project particularly valuable is that it is time-dependent [26]. The results of the evaluation might be completely different from one day to another, independently if the project is still underway, or after its closure

[26,42–44]. Priorities, needs, the point of view, or the result of an assessment can change quickly due to rapid changes in the environment [21,40]. If the project is evaluated months or years later, the assessment then should be strictly circumscribed to the project baseline and the defined assessment of its performance factors for the output (deliverables) during its lifecycle, outcome, and benefits achieved with the outputs in the defined environment.

Regarding R&D projects, measuring project success has become a fundamental concern for managers and executives in the last decades, and as a result, the issue has been extensively debated in literature [45]. However, determining whether an R&D project is successful is another subtle matter and a challenging task, as reaching top performance does not necessarily correlate with being successful. R&D projects are inherently complex, whit several dependent phases that make it even more difficult to determine their success factors.

A common approach is to decompose the success into measurable units of project success and project management success [43]. Other approaches differentiate even more in detail and use further parts as product success and business success. While project success relates to the objectives of the project plan, product success relates to meeting the product requirements and is further "reflected by use, satisfaction, and effectiveness […] in benefiting intended users" [46]. Business success is determined by the business strategy and is achieved when the funding organization has realized the expected benefits through the means of the project, as defined in the benefit-management plan.

In the end, project success cannot be expressed binarily as a "success" or a "failure", since the output might be a success, but the desired benefit could not be reached. Furthermore, a project that is closed prematurely because it is not viable, desired, or worthwhile anymore due to changes in the environment may not be considered a failure [47]. Consequently, if areas of the evaluated level are perceived as a failure, it is important to identify the root causes, which can lay in planning failure (the gap between what was planned and what was really accomplished) and/or actual failure (the gap between what was achieved and what was accomplished) [48].

Each project is unique, and therefore specific criteria are needed to do justice to that uniqueness. However, general success and failure criteria enable the comparison of projects [46]. Nonetheless, because project success can mean different things to different stakeholders, a common definition of project success for the individual project, as well as who, when, and how to measure it, must be determined and documented [24]. The success criteria need to be specified for project management, project activities, the output, the outcome, the benefit, and the business value [49,50]. This distinction is necessary since operating project outputs, regardless of results, provide organizational benefits.

Success management can be conducted at several levels, complementing each other to the top. Furthermore, the operation has its part in the success realization of the project portfolio of the organization, and consequently, the whole picture must be addressed. Although Figure 2 aims to show relationships, the success of each level is determined by the success criteria set forth and may not be entirely complementary in practice because different puzzle parts must be balanced. As a result, satisfactorily finishing all the project's activities does not mean that the program was a success. For this research, we focus on the area of project management. As a result, only this area and the operation area are covered, because projects typically produce deliverables that are then put into operation. In the future, more research into the other displayed areas should be undertaken.

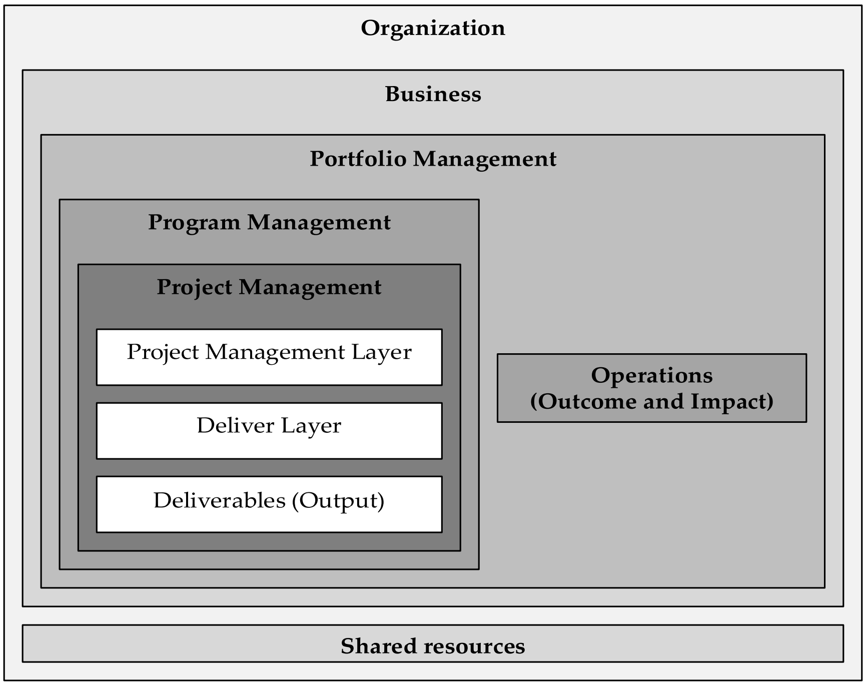

Figure 2. Project Success Levels.

2.2. Project Success and Stakeholders

The concept of project success and stakeholder involvement has evolved over the years. Davis provides an extensive, detailed, and exceptional analysis [29], from the 1970s, orienting the concept of success to the operational side, tools, and techniques [30] where communication with stakeholders was lacking at a general level [29] to the shift in the 1980s to examine the technical aspects of the project and how they related to the client organization [51], to conclude that success is dependent on the perception of success of the multiple stakeholders involved in the project and the time at which that success is measured [52]. This was the beginning of recognition of stakeholder involvement in project development as a Critical Success Factor (CSF) [53], taking the first steps towards understanding and recognizing the importance of project success from a stakeholder perspective in the 1990s [11], to finally recognizing that success is dependent on both internal and external stakeholders [54].

This story has been used by Turner [55] to present some necessary, but not guaranteed, conditions for project success, such as that the success criteria should be agreed with the stakeholders before the start of the project and continuously reviewed throughout the project, or that a collaborative relationship should be maintained between the stakeholders and the project manager, considering the project as a partnership, that the project manager should have the flexibility to deal with unforeseen events in the project, that the project owner should provide guidance on how the project should be carried out, and finally, that it is vitally important that the project owner takes an interest in the realization and development of the project.

Another important and related aspect is determined by correct identification and classification of stakeholders [28], and how according to this classification each stakeholder should be asked about specific issues according to their role in the project, as each one will analyze the project in particular according to their expertise.

In short, the role of stakeholders has gained importance over the years, evolving from a position of an observer to a crucial involvement in the success of the project [56], allowing them to have first-hand knowledge of the project development, to contribute their point of view in the decisions and to be an important part in determining the success of the project. When the perception of the success of the project from the point of view of the organization and the stakeholders is united, the success of the project is not automatically guaranteed, but nonetheless, the chance that the project will go ahead according to the initial objectives is much greater, making it crucial to agree from the beginning on the definition of the success criteria and the points of the project which will be evaluated as the project develops.

Furthermore, the measurement of project success is a controversial issue. According to De Wit, A. [26], it is illusory to objectively measure project success if one wants to take into account the objectives of all stakeholders throughout the project life cycle and at all levels of the management hierarchy. However, having a holistic project measurement is not the only problem, according to Millhollan and Kaarst-Brown [57]. Some of the factors that contribute to project success materialize while the project itself is being executed. Moreover, according to the same authors, some of the factors that contribute to the success of the project, both in the perception of the project manager and the stakeholders (perceived project success [58]), may not materialize until long after the project has been completed [59]. In addition, the success factors that are predefined for the project may conflict with each other during the project life cycle, as the fulfillment of some constraints may have a negative impact on the satisfaction of stakeholders' requirements.

A way to overcome this issue is to separate the dimensions of project success into several components: the measurement of project management success in terms of the iron triangle, project success understood as the fulfillment of the overall project objectives, and project success aligned with the project outcome, creating not only a dependent relationship between project management and project objectives, but also an evaluation after the project has been completed [60,61].

2.3. Project Success Dimensions

Success criteria are accepted and dependent variables, including principles and standards by which anything can be judged and defined [17,34]. These criteria should be evaluated under six important elements that guarantee a "consistent, high-quality evaluation within a common framework", according to the OECD. These elements are relevance, coherence, effectiveness, efficiency, impact, and sustainability [13]. Since success is dependent on the area which is inspected, these parts must be addressed individually, since although one area might be perceived as a failure, the other areas can still be perceived as successful.

Consequently, it is crucial to define the success criteria for different dimensions. Our research was limited to Project Management, Delivery Activities, Deliverables, and Operations according to Figure 2. These dimensions were chosen because of their relevance to projects and include the different stages of project development, and as mentioned before, those dimensions are where projects typically produce deliverables that are then put into operation.

2.3.1. Project Management Success Dimension

The main objective of the criteria summarized in this dimension is to allow the analysis of the project manager's performance in implementing the project plan. These criteria were formulated in 14 statements (numbers 1–14), as presented in Table 1.

Table 1. Project Management Success Criteria.

No.	Project Management Success Criteria	Reference
1	Completed within defined and agreed budget	[41,62]
2	Return on Investment of the project	[63]
3	Knowledge generation regarding project management (e.g., tools, techniques, approaches, processes)	[64]
4	Publications regarding project management (e.g., tools, techniques, approaches, processes)	[64]
5	Customer satisfaction regarding the management of the specific project	[34]
6	Project management processes were conducted within the organization's quality standard	[65]
7	Resources for project management activities were mobilized and used as planned	[51,66]
8	Attitude towards risks (risk tolerances)	[67]
9	Risk value (impact) of suffered threads (unknown unknown)	[68,69]
10	Project goal was achieved	[51]
11	Completed within defined and agreed scope	[41,62]
12	Reputation of the organization has increased	[66]
13	Reputation of the Project Management Office (PMO) has increased	[66]
14	Completed within defined and agreed schedule	[41,62]

2.3.2. Delivery Activity Success Dimension

The objective of the project result delivery layer focuses on the project activities and processes necessary to create the results. These criteria were formulated in 11 statements (numbers 15–25), as presented in Table 2.

Table 2. Delivery Activity Success Criteria.

No.	Delivery Activity Success Criteria	Reference
15	Resources for delivery activities were mobilized and used according to planned productivity measures	[66]
16	The activities required to produce the deliverables have a good reputation	[66]
17	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)	[70]
18	Publication regarding project activities	[64]
19	Client satisfaction with the quality of the activities required to produce the project deliverables	[71]
20	Delivery activities were conducted within the organization's quality standards	[65]
21	The way the deliverables are created contributes to sustainability	[64]
22	Process improvements were identified (idea/knowledge generation)	[72]
23	Process improvements have been applied, resulting in beneficial results	[7,73]
24	Technology transfer	[63]

2.3.3. Deliverable Success Dimension

This dimension describes the outcome of the project, and the success criteria set out here aim to verify whether the outcome of the project is in line with the purpose agreed with the stakeholders. These criteria were formulated in seven statements (numbers 26–32), as presented in Table 3.

Table 3. Deliverable Success Criteria.

No.	Deliverable Success Criteria	Reference
26	Completed within defined and agreed budget	[72]
27	Return on Investment of the project	[64]
28	Knowledge generation regarding project management (e.g., tools, techniques, approaches, processes)	[64]
29	Publications regarding project management (e.g., tools, techniques, approaches, processes)	[49]
30	Customer satisfaction regarding the management of the specific project	[64]
31	Project management processes were conducted within the organization's quality standard	[64]
32	Resources for project management activities were mobilized and used as planned	[64]

2.3.4. Operations Success Dimension

Projects create unique outputs which are then transferred into operations, where they should create the defined and agreed outcomes, impacts, and the desired value. Since outcomes and impacts might not be always in the favor of all stakeholders, the impact can be either perceived as a benefit or a disbenefit. Nevertheless, its success criteria need to verify that the operation ensures that the product is operated in an appropriate way, where it is fit for use [63]. These criteria were formulated in seven statements (numbers 33–39), as presented in Table 4.

Table 4. Operations Success Criteria.

No.	Operations Success Criteria	Reference
33	Operation stays within the defined budget	[41,62]
34	Operation delivers the desired outcomes (as the fundamental business objective (the fulfillment of the project objective) and that have been developed in accordance with the core competencies of the organization)	[64]
35	Operation delivers the desired impacts (expected benefits evaluated for the project portfolio as a whole)	[64]
36	Operation delivers the desired value (the performance measures in the conduct of operations)	[71]
37	Actual use by the customer	[51,74]
38	Workplace security	[69]
39	Downtime (e.g., maintenance, repair)	[69]

2.4. Success Measurements

To measure success, specific tolerances need to be defined. For each assessment area, success and failure criteria should be defined to gain a better understanding, avoid wrong expectations, and foster a clear and understandable communication. This can be achieved, for example, by using control charts.

To achieve this, these criteria and tolerances must be collected from all (key) stakeholders from the beginning of the project to analyze if the requirements are viable, desirable, and achievable [40]. All stated and agreed target values and limits need to be SMART (Specific, Measurable, Achievable, Realistic, and Timebound). After that, these requirements and expectations need to be balanced and managed [75,76], since different levels or areas could conflict with each other or be contrary. Then, problem solving must be applied to balance these or to identify higher priorities and to find, in the best case, acceptable solutions for all stakeholders.

Several factors can influence these processes, which are highly dependent on the situation. Furthermore, success criteria can be defined with a weighting factor or as primary or secondary [48]. The different views on the defined success criteria from (key) stakeholders should be collected and deviations should be discussed. In case parties cannot understand each other or disagree with some points which would create conflicts, a third (neutral) party can be involved, which can moderate to reach a consensus as well as conduct an assessment from an independent standpoint, or to accept knowingly an unsatisfied stakeholder with expectable consequences. All of this must be contained in the project management methodology as a formal step to control and assure that the right criteria will be considered.

Moreover, as described before, success is not a one-time definition. It evolves and develops over time. Consequently, the definition must be continually revised if needed. Along with that, it needs to be defined when and how the success can be measured. Another point which influences the assessment of success or failure is the person who conducts the assessment [24,62]. As stated before, general success criteria need to be developed for an organization to be able to compare projects. Nonetheless, distinct criteria need to be defined to do justice to the uniqueness of each project [46].

Another complementary step to assess the success of projects is to define the Key Performance Indicators (KPI) to control if the project is on track [45]. The definition and measurement of these KPIs must go hand in hand with the success criteria defined in the organization to be able to measure the performance of a project with real criteria.

2.5. Q-Methodology

Q-Methodology is one of the oldest statistical methods, originally created for psychoanalysis to understand humans' "unconscious mental processes" [77]. Based on the history of this methodology, the goal is to find the statistical explanation of humans' "mind" [78]. The Q-Methodology is known as a statistical tool for understanding the personal view of individuals on a specific matter, which is mostly based on the reality and pleasure–pain principles created by Sigmund Freud [77,79]. Sigmund Freud explored the pleasure–pain principle (originally in German "Lust–Unlust"), which describes the distribution of the given information based on the subconscious wishes of reality. Reality creates circumstances to the external world based on decisions made and is also closely aligned with consciousness, which is a significant point of every decision [77]. Unfortunately, reality usually differs from humans' desire, and even an individual can disagree with the real situation in the environment. This influences subconscious processes and must be considered while analyzing results of the methodology. As stated before, Q-Methodology is not only used for psychology research but is also extended to a variety of experiments that require statistical data based on the personal point of view of the participants.

Q-Methodology is a semiquantitative technique that can help to identify stakeholders' view on a specific topic. This methodology demands that a set of statements, a so-called Q-set (n), must be distributed within a range, i.e., ranking grid, from a given P-Sample (number of respondents) [79]. The original version of Q-Methodology consists of a set of 48 statements (Q-set (48)) which must be ranked on a grid within the range from −4 to +4, where −4 is equal to "un-pleasure" and +4 is equal to "pleasure" [78].

To be able to identify different subjective perspectives on project success from PMs and stakeholders for a public–private research organization, the study deployed Q-

Methodology as the research strategy. Q-Methodology has shown its usability in the context of project management research; for example, Silvius et al. [80] use Q-Methodology to investigate the consideration of sustainability aspects in the decision-making processes of PMs, concluding that the consideration of sustainability principles is underrepresented compared to the triple-constraint criteria. According to Brown [81], Q-Methodology adds to a PM's techniques and tools by making it possible to learn what stakeholders think about non-specified requirements, providing stakeholders and PMs more information for troubleshooting project threats. Cuppen et al. [82] used Q-Methodology to contribute to proactive risk mitigation and to reveal hidden perspectives on industrial projects, leading to better project management. Mardaras et al. [83] used it to investigate whether organizations in R&D environments have antifragile characteristics. Finally, Brown [84] provides a foundation for the systematic study of subjectivity, a person's viewpoint, opinion, beliefs, and attitude.

3. Research Design

This paragraph presents the research strategy and research design of the study. As the literature review showed that success is a multidimensional concept and that a clear understanding of how PMs integrate the project success concept into their decision making is lacking in literature, the nature of the study is explorative.

As shown in the Conceptual Framework (Figure 3), this paper proposes a way to bridge the gap between what success means to an organization and to its stakeholders in the context of an R&D project conducted in a public/private collaboration on a KTTO. To achieve this, literature on project success was analyzed to convert the different aspects identified into tangible units, allowing us to define and organize the success criteria of a project in different dimensions. Subsequently, using Q-Methodology, the PMs of the KTTO and their main stakeholders were asked about which criteria, within the previously identified dimensions, were most important to them, which allowed us to determine the main success criteria of an R&D project for a KTTO and its stakeholders.

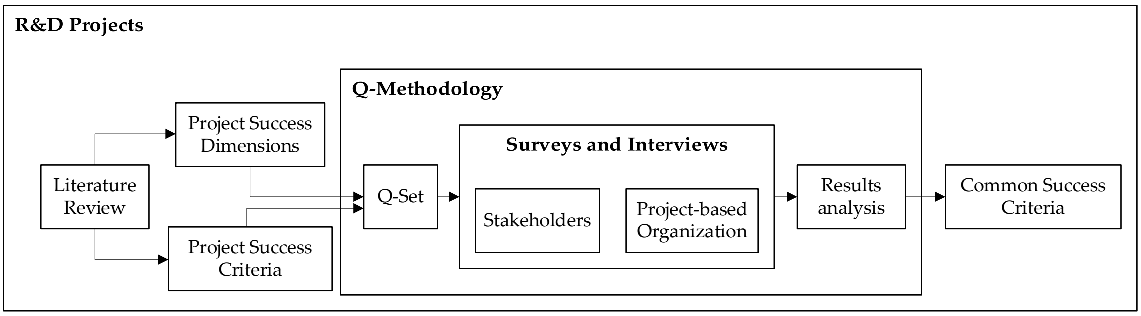

Figure 3. Conceptual framework.

3.1. Q-Methodology Approach

In a Q-Methodology study, respondents are typically presented with a sample of statements about a given topic, known as the "Q-set". The "P-set" of respondents is asked to rate the assertions from their point of view, using a quasi-normal distribution (Figure 4). The respondents disclose their subjective point of view [85] or personal perspective [86] by "Q-ranking" the assertions.

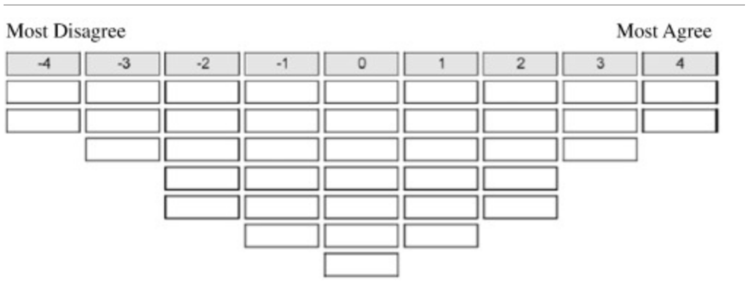

Figure 4. Sample Q–grid .

The Q-Methodology traditionally intends to give a picture of the perspectives that exist (the variety of perspectives) among the population, rather than analyzing the level of support for those perspectives among the population (the balance of perspectives). It also relies on purposive sampling and smaller sample sizes. The fact that there is a person who is assumed to have a different point of view is enough reason to include him or her in the sample. Correlation between personal perspectives then implies the existence of similar viewpoints or segments of subjectivity [87]. Q-factor analysis provides information on similarities and differences in the viewpoint on a specific subject by correlating people.

For this research, only internal stakeholder perspectives (a short characterization of the internal stakeholders can be found in Table 5) were collected to identify the applicable success criteria for R&D Centers, which in turn may apply for the CFAA.

Table 5. The CFAA's Internal Stakeholders.

Stakeholder Classification	Description	Characteristics	Quantity
Type A	Principal members	Founding Partners	2
Type B	Full members	Machines manufacturers	8
Type C	Full members	Components manufacturers	14
Type D	Limited members	Components/software/machines manufacturers	68
Collaborating partners	Limited members	Institutes, Associations, Sectorial clusters	8
University	Full members	University of the Basque Country and several research groups	1

To define the applicable success criteria, the Q-Methodology procedure with the subsequent steps were followed:

- Reviewing the existing success criteria of the CFAA.
- Defining new criteria, based on the literature.
- Performing a trial run of the Q-sort.
- Revising statements for the final Q-sort with the CFAA's internal stakeholders.
- Perform Q-sorts with the selected stakeholders.
- Assessing gathered data by using the software from Aiora Zabala [88].
- Interpreting results (factors) from the software.

The first step of the defined procedure was to evaluate existing criteria of success of the project in terms of relevancy to the current research and revising unclear statements. To assess the criteria developed by the previous research at the CFAA, brainstorming was used as a method for eliminating, extending, or changing the unclear criteria. The case study was conducted by members of the CFAA's Project Management Office.

As mentioned previously, the original version of Q-Methodology consists of 48 statements [78]. In this case, the grid was reduced to 25 cells to reflect the current number of statements. Further statements could have been identified; however, most of the participants were overwhelmed by many options, since this type of experiment had never been conducted before at the CFAA. Subsequently, 25 statements were generated and a table with the range from −4 to +4 was formed. The meaning of the ranking was slightly adjusted so that +4 represents "the most important criteria" and −4 represents "the least important criteria" in terms of their own perspective as an employee or internal stakeholder of the CFAA. As it is crucial that the distribution reflexes their own view and not the organizational viewpoint, this issue was pointed out to the participants.

To ensure that the defined Q-set is understandable, and the formulations are unambiguous, a trial version of the Q-Methodology survey was conducted. In the trial evaluation of the new criteria, six people from different positions in the CFAA participated. Before the trial run was conducted, the general principle of Q-Methodology was explained and a short introduction of the performed research was provided. The trial run was conducted in groups of two, to enable discussions, since people often struggle to express their thoughts loudly. Since the first interviews were conducted on a trial basis and the aim was to understand whether all statements are clear and easy to understand, it was not necessary to apply the procedure individually. By the end of the editing the statements, 30 final improved statements were prepared for the final Q-Methodology interviews.

3.2. Statements

A literature review of the main success criteria for each of the dimensions proposed was carried out. This understanding forms the foundation for the empirical part of our study, in which we explore how PMs consider these dimensions of success in their decision making. These criteria were found thanks to a literature review and were defined through semi-structured interviews with the organization's project team, who assessed each of the selected criteria by the formulated questions of the OECD [13], and to ensure that the criteria to be evaluated were not decontextualized from the organization.

In the study, the respondents were asked to rank the 30 statements divided among different categories according to the PMBoK [72] on a score sheet, as in Figure 4, about how important each of the different success criteria were for them during the execution of a project (Table 6). The statements were related to aspects to be considered as success criteria for the projects carried out in the organization. The "umbrella question" for the statements was formulated as "how important for the success of the project is to/the/that", with each statement completing this sentence. For example: "how important for the success of the project is the attitude towards risk (risk tolerances)".

Table 6. Final Q-set.

Item	Statements	Success Dimension	Category
1	Attitude towards risks (risk tolerances)	Project Management	Risk Management
2	Complete within defined and agreed budget	Project Management	Cost Management
3	Complete within defined and agreed scope	Project Management	Scope Management
4	Complete within defined and agreed schedule	Project Management	Time Management
5	Customer satisfaction regarding the deliverables	Deliverable	Quality Management
6	Customer satisfaction regarding the management of the specific project	Project Management	Project Management
7	Client satisfaction with the quality of the activities required to produce the project deliverables	Delivery Activities	Quality Management
8	Degree to which the deliverables meet their intended purpose	Deliverable	Quality Management
9	The activities required to produce the deliverables have a good reputation	Delivery Activities	Stakeholder Management
10	Delivery activities were conducted within organization's quality standard	Delivery Activities	Quality Management

11	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)	Delivery Activities	Knowledge Management
12	Knowledge generation regarding project management (e.g., tools, techniques, approaches, processes)	Project Management	Knowledge Management
13	Project goal was achieved	Project Management	Scope Management
14	Project management processes were conducted within organization's quality standard	Project Management	Quality Management
15	Publications regarding project activities (e.g., tools, techniques, approaches, processes)	Delivery Activities	Knowledge Management
16	Publications regarding project management (e.g., tools, techniques, approaches, processes)	Project Management	Knowledge Management
17	Reputation of the organization has increased	Project Management	Stakeholder Management
18	Reputation of the Project Management Office (PMO) has increased	Project Management	Stakeholder Management
19	Resources for delivery activities were mobilized and used according to planned productivity measures	Delivery Activities	Resource Management
20	Resources for project management activities were mobilized and used as planned	Project Management	Resource Management
21	Return on Investment of the project	Project Management	Cost Management
22	Risk value (impact) of suffered threads (unknown unknown)	Project Management	Risk Management
23	Workplace Security	Operations	Risk Management
24	The deliverables, in terms of their design and creation, are adequate in terms of direct sustainability impacts	Deliverable	Sustainability
25	The deliverables, in terms of design and creation, are adequate in terms of indirect sustainability impacts	Deliverable	Sustainability
26	The deliverables meet official standards (e.g., ISO)	Deliverable	Quality Management
27	The deliverables meet the defined quality criteria	Deliverable	Quality Management
28	The product is characterized as sustainable	Deliverable	Sustainability
29	The way the deliverables are created contribute to sustainability	Delivery Activities	Sustainability
30	Workplace Safety	Operations	Risk Management

3.3. Data Collection

Data collection was carried out through structured, individual interviews to obtain the personal perspective of each participant in the experiment and to receive their opinion on the success criteria of the project. This experiment was conducted manually by providing a Q-grid (Figure 4) with cards (statements included in Table 6) on paper.

3.4. Respondents

The respondents in the study were selected from different types of partners and industries of the CFAA and different roles inside the organization. They were all experts and experienced PMs within privately held companies, working closely with the CFAA, and developing R&D projects and having the responsibility of decision making in projects or influence on decisions. In total, 20 respondents participated in the study. The respondent classification is shown in Table 7.

Table 7. Respondent classification.

Role	Group	Profile	Number of Respondents
Stakeholder	Type A	Project Manager	4
	Type B	Project Assistant	1
		Project Manager	1
	Type C	Project Manager	2
	Type D	Project Manager	1
	University	Project Sponsor	3
Organization	CFAA	PMO	3
		Project Manager	5
Total			20

As for the experience and expertise of the participants chosen for this exercise, this was an absolute requirement for the authors, as they needed people who were familiar with project management theory and the different elements that make it up, as well as having the necessary practical experience (minimum 5 years conducting project management work in their organizations) to be able to analyze their responses much better and have greater relevance for the conclusions of the study.

4. Results and Discussion

The individual Q-sorts of the respondents were analyzed to reveal a limited number of perspectives in which the statements were sorted by the respondents. To analyze the results, the web application [88] from Aiora Zabala was used for the evaluation of the Q-sorts. This software aims to analyze data using Q-Methodology. It also offers all the options for standard Q-analysis, such as different extraction methods, rotation, and forced and unforced distributions [89]. The data processed by the online software were analyzed according to three factors, the significance of which is indicated below.

4.1. Factor Analysis

The first step is to group the participants according to the views they have in common. For this, it is necessary to perform a factor analysis, which will show the similarities between the participants' ranking of the statements in the Q-grid [90]. Varimax rotation was used to ensure that the factors analyzed explained the maximum amount of study variance, and Pearson has been used for the correlation coefficient. Due to the relatively small number of Q-sorts, only a factor analysis with three and four factors was conducted. Since the factors analysis with three factors are more meaningful, these built the basis for further analysis (Table 8). The three factors explain 62% of the total variances (Table 9).

Table 8. Factor analysis.

Role	Participant	Factor		
		f1	f2	f3
Stakeholder	UNI1	0.6904	0.2107	0.353
	UNI2	0.227	0.5606	0.071
	UNI3	0.5991	0.2246	−0.108
	TA1	0.7708	0.3909	0.157
	TA2	0.3734	0.5379	−0.496
	TA3	0.5417	0.4273	0.148
	TA4	0.6105	0.5798	−0.093
	TB1	0.7492	0.0571	0.101
	TB2	0.6559	0.0229	−0.543
	TC1	0.1002	0.842	0.082

Organization	TC2	0.7888	0.3696	0.051
	TD1	0.1211	0.8275	0.112
	PM1	0.2101	−0.0092	0.764
	PM2	0.4162	0.6386	0.118
	PM3	0.5793	0.2215	0.368
	PM4	−0.0023	0.2482	0.727
	PM5	0.3628	0.1994	0.548
	PMO1	0.4818	0.4573	0.385
	PMO2	0.7198	0.2865	0.383
	PMO3	0.2818	0.6981	0.29

Table 9. General factor characteristics.

	Average Relation Coefficient	Number of Loads *	Eigenvalues	Explainable Variance	Reliability	Standard Error of Factor Scores
Factor 1	0.8	10	5.4	27	0.98	0.16
Factor 2	0.8	5	4.2	21	0.95	0.22
Factor 3	0.8	3	2.7	14	0.92	0.28

* Only 2 people were not grouped to a factor.

4.2. Factor Interpretation

Following factor interpretation, and answering RQ2 (Table 10), it was very interesting to see that achieving the project goal was the most important criteria for the success of a project. It is logical, after all. However, the fact that the focus is so strong on the achievement of the goal is curious. Finding a reason for this is rather complex as it may be due to cultural factors, personal factors, organizational culture and directives, PM background, or further influences. This strong focus might also explain why more than 80% of the projects initiated in the CFAA as of 2020 were completed and successfully delivered to the partners.

Table 10. Top-ranked statements for stakeholders and the organization.

Item	Statements	Success Dimension	Category
13	Project goal was achieved	Project Management	Scope Management
7	Client satisfaction with the quality of the activities required to produce the project deliverables	Delivery Activities	Quality Management
11	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)	Delivery Activities	Knowledge Management
30	Workplace safety	Operations	Risk Management
8	Degree to which the deliverables meet their intended purpose	Deliverable	Quality Management
21	Return on Investment of the project	Project Management	Cost Management
5	Customer satisfaction regarding the deliverables	Deliverable	Quality Management
27	The deliverables meet the defined quality criteria	Deliverable	Quality Management
17	Reputation of the organization has increased	Project Management	Stakeholder Management
9	The activities required to produce the deliverables have a good reputation	Delivery Activities	Stakeholder Management

The success dimension of the project is the most important statement and is related to those grouped under project management. This may be due to the distribution of the dimensions within the Q-set, but also to the apparent importance of how the project is managed both internally and externally. Aspects related to the deliverables are also very well-represented in this sample (60%), reflecting once again that as important as it is to achieve the project objective, it is also important that the final product of the project, as well as the activities that were carried out to deliver it, are well-managed. Of these statements, 40% are considered related to quality management, which is not enough if the quality of the work carried out is not considered.

The generation of knowledge within the project is an aspect to highlight. The processes, techniques, tools, and methodologies followed to achieve the project's objective must be documented and delivered to the project owner. This makes the subsequent implementation at the client's premises easier.

Among the lowest-ranked statements (Table 11), it is worth noting that the risk impact of the threats suffered (unknown unknown) was the lowest-ranked statement. This may be since the organization has not carried out a correct identification of risks for the projects carried out. However, it is also recognizable that risks are more common in R&D projects. Both internal and external staff should be aware of the importance of a correct risk management for the project, where these risks can be identified, catalogued, categorized, and ranked to be able to propose preventive measures.

Table 11. Bottom-ranked statements for stakeholders and the organization.

Item	Statements	Success Dimension	Category
16	Publications regarding project management (e.g., tools, techniques, approaches, processes)	Project Management	Knowledge Management
18	Reputation of the Project Management Office (PMO) has increased	Project Management	Stakeholder Management
29	The way the deliverables are created contribute to sustainability	Delivery Activities	Sustainability
24	The deliverables, in terms of their design and creation, are adequate in terms of direct sustainability impacts	Deliverable	Sustainability
28	The product is characterized as sustainable	Deliverable	Sustainability
14	Project management processes were conducted within organization's quality standard	Project Management	Quality Management
25	The deliverables, in terms of design and creation, are adequate in terms of indirect sustainability impacts	Deliverable	Sustainability
26	The deliverables meet official standards (e.g., ISO)	Deliverable	Quality Management
10	Delivery activities were conducted within organization's quality standard	Delivery Activities	Quality Management
22	Risk value (impact) of suffered threads (unknown unknown)	Project Management	Risk Management

Another aspect to highlight is the sustainability of the project. All the sustainability-related criteria defined in the Final Q-set (Table 6) are among the bottom-ranked statements for the internal stakeholders and the organization, although for the TRL in which the CFAA works, sustainability is a determining factor for the subsequent implementation of the project results at the client's facilities. This may be due to different reasons, such as a lack of awareness of the importance of sustainability in the activities beyond the immediate achievement of project results. Different cultural aspects can be evaluated to find a reason, or even the lack of conducting risk identification exercises at the organizational level may explain why for respondents it is not a determining factor in assessing the success of a project. Further research on this aspect can be developed, not only at the level of the organizations studied, but in the general context of project management.

These results at the organizational level should lead to efforts to improve the quality of the work carried out, managing it from the initial stages of the project to achieve the ultimate objective of the project, but with a special emphasis on the quality of the activities carried out. A project management methodology that allows this control is of vital importance for the Center and its stakeholders.

It is worth recognizing that the three factor-groups included compliance with standards, which reflects the awareness of PMs and stakeholders on this issue. In general, activities that lead to understanding and conveying the importance of these standards within the work performed are of great importance for the Center and the realization of R&D projects.

Responding to RQ2, the subjective perspectives are grouped on factors, which are named and described shortly, based on the results of the Q-analysis:

4.2.1. Factor 1: High Quality-oriented to the Output

This group is characterized by getting the job completed properly. This includes focus on workplace safety, meeting official standards for deliverables and creating customer satisfaction regarding deliverables, as well as the project activities to create the output. This group focuses on fulfilling customer expectations and increasing the reputation of the organization.

This group is mainly composed of the organization's stakeholders, which makes it logical to appreciate that the objective of the project and the activities to be carried out should be carried out with the highest possible quality. It also focuses on the importance of creating knowledge of both project activities and project management, a further quality of R&D project management.

4.2.2. Factor 2: Traditional Project Success-oriented

The people in Factor 2 can be described as focused on general objectives. They want to stick to plans, such as adhering to scope statements and schedules, but also official standards to make the project successful for the organization. However, external knowledge sharing is not considered as their main priority.

Customer satisfaction is an important element for this group of people. An interesting aspect for further analysis is that this group is mostly made up of stakeholders. More experience in project management, a better definition of objectives in their companies, and more demanding controls for project management may be reasons for this majority. Additionally, the people grouped under this factor have a higher correlation based on the chosen statements with the people in Factor 1 than with the people grouped under Factor 3, which further indicates a strong inclination towards Project Quality Development by this group.

4.2.3. Factor 3: External View-Oriented

This group is heavily focused on the outside, which is represented by project goal achievement and customer satisfaction, knowledge generation and publications, and increasing the reputation of the organization. Changes regarding the scope and time are accepted to ensure customer satisfaction. It is also characterized by the acknowledgment and fulfillment of the official standards of the activities developed during the project, which is a characteristic that this group choose from the statements as one of the most important to them.

In general, this group matches most of the goals of the CFAA and seeks to help on the development of applicable advanced manufacturing technologies and a quick transfer of this knowledge for both partner companies of each project and local industry.

5. Conclusions

A project can no longer be seen only as a temporary endeavor undertaken to create a unique product, service, or outcome. Although the objective is the same, the elements that constitute it increase, and must be seen as a system in which the inputs directly determine the outputs, with all the elements that compose it developed in one or several organizations with certain practices and customs, in which PMs, influenced by a series of elements, can make decisions that compromise the final success of the project according to the stakeholder's criteria. Being able to understand this complexity and to analyze it point-by-point is what determines the success of the project.

A major concern for the organization was to identify which were the most important success criteria when evaluating or considering a project successful. The identification of these criteria in the literature, the subsequent discussion to define them, and the exercise developed in accordance with Q-Methodology provided us with the possibility to create a list of what these criteria are. With the results obtained, it is now possible for the PMs of the organization, as well as the members of the Project Management Office, to make plans, set indicators, and define methodologies and new control points in which the fulfillment of the quality criteria identified in this study can be evaluated, not only at the end of the project, but also during the whole lifecycle.

Another important aspect of the research is that it is easily applicable to other types of organizations. Thanks to the analysis of the literature, we have shown how important it is to know the stakeholders' point of view for the success of the project, and how this is not exclusive to R&D organizations that carry out collaborative projects, but to any other organization that carries out projects.

To conclude on RQ1, the most important criteria were identified and analyzed in Section 4. About RQ2, the factor-group 1 comprised 50% of the participants. As described in chapter 4.2, this group is focused on delivering high-quality outputs. Nonetheless, as the factors show no greater majority and the participant size was limited, this can be interpreted as an indicator. However, the results can be used to improve the project approach in R&D projects, and to evaluate the success of such projects. Depending on the context of the project, these criteria might be introduced or used to re-weight existing metrics and KPIs.

6. Limitations

There are several threats to the validity of this study, particularly about subject sampling and external validity. The subjects who participated in the survey were chosen because they were the most important people in their organizations related to the CFAA and were the ones who had spent the most time working closely with them. At least one participant was chosen from each type of CFAA partner, however, having only one participant from the type D partner (Table 5) may not be appropriate, as this group of partners is the largest, with more than 50% of all CFAA partners. Furthermore, the participant group is small and might not be representative. Consequently, this research and approach should be taken further on a greater scale to validate the findings.

7. Future Research

As explained above, the criteria for defining whether a project is successful or not depend on a series of factors related to the point of view, or the moment at which the measurement is made. Future research is needed to further study the reasons behind the lack of success of the projects carried out in the organization, to determine and analyze whether they are related to the success criteria evaluated here.

Furthermore, to overcome some limitations, this research and approach should be taken further on a greater scale to validate the findings. This might strengthen the factors found or introduce new factors.

It is also important to evaluate how these success factors evolve. Changes in client requirements, organizational conditions, and the context in which the project is developed are factors that affect which criteria determine whether a project is successful or not, so it is interesting to know how and why the evolution in the success criteria determined for a project is due. A complementary part of this study could have been to compare the currently perceived success or failure of the projects of the organizations against the analyzed factors, to evaluate these as a kind of test of the factors found.

As a natural and logical next step, a project management approach in which these success criteria are considered, aimed at continuous quality assessment during the project life cycle, should be developed. Additionally, with the use of this approach and having measured the success criteria for a particular project, it would be possible to analyze whether these criteria are really adapted to the reality of the organizations or whether, on the contrary, they fail to measure some aspect not considered.

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Identification of Key Performance Indicators in Project-Based Organisations through the Lean Approach

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Abstract: For the time being, companies and organisations are being forced to compete in utterly complex and globalised environments, facing massive natural, economic, and technological challenges on a daily basis. Addressing these challenges would be impossible without a proper approach that helps them identify, measure, understand, and control the performance of their organisations. Lean principles and techniques rise as a solution. This paper justifies and proposes the use of lean principles and techniques to identify key performance indicators (KPIs) in project-based organisations based on their organisational and operational needs. The research focuses mainly on the identification and categorisation of KPIs through a qualitative approach, based on systematic literature review (SLR) of performance indicators, project management, and project success. As a case study, an analysis of relevant information of an R&D and innovation project-based organisation, such as quality manuals, a benchmarking process, internal studies, and surveys regarding what success means for different kinds of stakeholders and for the organisation itself was conducted. As a result, this research is of a high value for project-based organisations, especially those that are not apprised of how to correctly formulate a series of KPIs, or whose path to it is still not clear.

Keywords: lean; key performance indicators; DMAIC; CTQ; project success; project-based organisations; technology readiness level

1. Introduction

Nowadays, organisations are forced to compete in utterly complex and globalised environments, facing massive natural, economic, and technological challenges on a daily basis. Addressing these challenges would be impossible without noticeable management of the performance of their business. It is essential to every business, no matter the size, scope, or resources to identify, measure, understand, and control the progress of that performance [1,2]. Measurement systems are needed to set organisational goals and to control the improvements by monitoring the effectiveness and efficiency [3]. A common approach to carry out these measurements is through the use of KPIs metrics. KPIs provide an objective criterion for measuring business activities and project success [4] and are a remarkably important part of corporate strategy for forecasting, measuring and planning business [2].

However, it should be noted that performance metrics vary in their purpose, definition, and content. Therefore, different methodologies are used to define and select the business KPI's, to make sure that they match the competitive environment and strategy. According to Iuga et al. [2], three important criteria need to be taken into account for the optimal selection: Validity, helpfulness, and relevance; and to ensure that the measurement system is under control a disciplined methodology is needed.

The lean approach has been explored for defining, measuring, and monitoring performance. The methodology focuses on continuous process performance improvement and enables decision making based on real facts and data analysis, information and objective evidence gathered through quantification and estimation methods [2,5]. The lean concept is characterised by managing the efficiency and effectiveness of the organisation, by putting the emphasis on customer value and waste reduction.

So, lean consists of a set of principles and tools that have been implemented in a broader range of industries [6,7]. Although its origin was within manufacturing, it has also been applied in non-industrial organisations such as services [8], banking, or healthcare [9]. Also, lean focus has expanded in a broad range of disciplines like sales, product development [8], project management (PM), and Research and Development (R&D) [6,10]. Although R&D is a new concept, some studies on lean R&D have been published, especially in the field of healthcare [6,7,11].

Despite the fact that the mentioned concepts have been studied, a lack of homogeneous process for identification and measure of KPIs was detected. Although the adoption of KPIs in order to achieve objectives within the production environment is widely spread [8], there is scarce research published on developing a model to identify the KPIs in project-based companies.

Literature concerning KPI's in a project-based organization context is generally related to project success [4,12,13]. The measures on which the success or failure of a project is judged are the success criteria and the KPIs are the factors that constitute those success criteria [4]. Project management KPIs are crucial as they enable the progress of projects to be monitored. It must be ensured that KPIs are aligned with the organisation's strategies, that the perspectives of all stakeholders are considered and that short- and long-term benefits are covered [12]. Regarding the relationship between project management performance and project success in project-based organisations the KPI's of the project management are the most significant variables for the success of a project [12].

Measuring R&D and innovation (R&D&I) project performance and if a project is successful or not in project-based companies has become a fundamental concern for managers and executives in the last decades. As a result, the issue has been extensively debated in the literature. However, determining whether an R&D&I project is successful is a subtle matter [14] and a challenging task. If someone is able to reach the top performance on your project, it does not guarantee that particular project will be successful.

R&D&I projects are complex per se, with several dependent phases that makes it even harder to determine project success factors criteria. It is clear that projects usually have multi-dimensions, and that different people involved in the project have different priorities. Therefore, not only should several dimensions for assessing the project success be considered, but also the fact that project success may vary over time based on different people's interest [15]. Davis [16] stated that different project success dimensions (PSDs), such as time, mission and objective, project manager competencies, strategic benefits, and top management support, have different importance for different stakeholders.

This paper justifies and proposes the use of lean principles and techniques to identify KPIs in project-based organisations. A qualitative approach, based on SRL, was adopted, which was used to analyse and compare research about project success and the use of lean for the identification of performance metrics. Using the SLR output, a lean-based KPI model is proposed with the aim of being a guide for the identification of performance indicators in project-based organisations. For the elaboration of this model, Lean Six Sigma process so-called DMAIC (define–measure–analyse–improve–control) as a cycle-based approach [17] was followed and adapted. Later, the model was validated through a case study in a R&D project-based organisation. Since the focus of this paper is on the identification and categorisation of KPIs, the validation, adequacy, and control of KPIs are recommended as future research.

This research will answer practical questions about how lean tools and principles lead to KPIs identification and which are the benefits from it. Additionally, it will be shown how a model for the identification of KPIs developed with lean will benefit project-based organisations.

In Section 2, we will expand the research methodology and how it leads us to the Literature Review (Section 3). Next, in Section 4, the definition and description of the model will be discussed, followed by the description of the Case study in Section 5. The results of the utilisation of the model will be shown in Section 6, and general conclusions and future research will be given in Section 7.

2. Research Methodology

To identify and examine the current state of the art of the research topic an SLR was followed. The process starts with the description of the research questions stated in the Introduction. Then, databases to be used to search the publications were chosen. To fill the keywords in the databases, Boolean "AND" operator was used to combine the keywords and to focus the results of the search. The range of years was not specified in order not to limit the number of publications. Nevertheless, it was observed that most of the research done on the subjects in question was published during the previous 20 years.

In the third step of the SLR, the documents identified were selected according to the exclusion and inclusion criteria. The central focus of the study was the relationship between project success, lean, and performance indicators in project-based context. In the scope, it was included subjects such as the use of lean for the identification of performance indicators; the use of lean tools and principles for KPI development; project success criteria; and KPIs in project-based companies. This last subject was selected to establish a context for the case study. Different types of documents were sought for distinct parts of the investigation. The SLR process continued with the fourth step of analysing the publications through thematic analysis and synthesising the information gathered. The last step consisted of reporting and using the findings, which will be discussed in the Literature Review section.

3. Literature Review Discussion

Lean is defined in many ways, some authors call it methodology, others philosophy [18], yet there is a common consensus on its approach. In the literature, lean is explored from two broad ways: Strategic and operational. The first is associated with lean principles and goals, while the second refers to practical aspects related to its implementation, tools and techniques [5].

Lean is based on five fundamental principles: Defining value from the customer perspective, identifying the value streams, making the value flow, implementing pull-based production, and striving for perfection continuously [5]. It also focuses on waste elimination by improving process performances and value creation [5,8,18]. The term waste in lean context is defined as an event or process that does not reflect customers value or generate any added value to the final output [2]. Seven types of waste are usually described in lean literature: Transport, inventory, motion, waiting, over-processing, overproduction, and defects [19]. Other researchers include an eighth kind of waste, the unused people's creativity [2]. Cherrafi et al. [19] highlighted another concept to be considered, which is sustainability (economic, social, and environmental concepts) due to an increase in the environmental and social awareness.

The lean approach to customer value and the elimination of waste leads to the identification of an organisation performance indicators. Waste has a direct impact on performance [19]; hence, some authors have researched on the definition of KPIs based on these types of waste. Iuga et al. [2] explored KPIs selection criteria based on the same waste categories. The link between KPIs and the lean waste concept enables a wider perspective on the performance assessment analysis [18].

3.1. Lean in Project-Based Organisations/R&D

Even though lean in R&D is a rather new approach [6], there are studies from years ago that have explored the use of lean for performance improvement within this discipline. Marti [11] explains how Lean Six Sigma leads to a better understanding of crucial customer requirements providing more value to services and to focus on improving critical areas of the R&D process. On the other hand, recent studies have also shown a positive impact in the implementation of lean within this area. Foruhi et al. [10] demonstrate how lean principles and tools in R&D organisations can improve their key skills by increasing efficiency and reducing waste and therefore costs. Al et al. [6] developed a model using lean to map and improve the functions of R&D project activities. Foruhi et al. [10] identified and determined the customer value as the main focus of lean concepts and how can be applied to all disciplines including R&D. Hence, Panat et al. [20], through a case study, demonstrated the benefits of using lean combined with Six Sigma methodology in the infrastructure and operations of the R&D organisation.

Lean can be used in conjunction with other improvement methodologies such as Six Sigma. Lean Six Sigma has been studied as a business strategy and methodology to measure and improve operational performance [11]. By integrating the tools, techniques, and principles of both methodologies, it achieves to eliminate defects in processes and improves process performance focusing on customer value [11,19]. Lean Six Sigma is also used on projects with the aim of improving the process through workflow creation and elimination of variation [21].

3.2. The DMAIC (Define, Measure, Analyse, Improve, Control) Methodology

The DMAIC is a Lean Six Sigma method consisted of five process phases: Define, measure, analyse, improve, control. In this study, the central idea behind DMAIC process is used for the creation of a lean KPI model by remaining focused on customer value.

3.2.1. Define Phase

In this phase, the scope of the project is aligned with the organisation strategy to detect in which aspects the performance meets or not the customer needs [11]. One of the lean tools for identifying the needs and requirements is the voice of the customer (VoC) [22]. The information captured with the VoC can be used to identify performance indicators.

Through VoC, critical requirements of the client and what he considers as value can be identified. By collecting the customer's needs, the information can be structured in a hierarchical way prioritized in terms of relative importance and customer perceptions of performance [22,23]. In addition to the VoC, there is the voice of the business (VoB), which concerns what the organisation aims to achieve [17].

3.2.2. Measure and Analyse Phase

During the measure phase, the VoC and VoB specifications are translated into measurable and controllable factors (quantitative data) through the critical to quality (CTQ) tool. The CTQs are specific quantifiable metrics that are linked to the organisation objectives [24]. This tool displays the customer's expectations towards the quality of a product. The CTQs are represented with a flow-down tree and when applied for performance indicators, some authors refer to them as CTQ [25]. Figure 1 shows the generic representation methodology or a project where there is an input (e.g., requirements, statements) provided by a stakeholder (e.g., supplier, customer), where there is a process to deliver an output [13]. In Lean Six Sigma, there is a similar mapping of a flow process known as SIPOC (supplier, input, process, output, customer) [20]. This diagram also works as a guide to identify metrics as KPIs. In CTQ context, the outputs are represented by Ys and the factors that impact them, and the inputs by Xs [21].

The CTQs are considered as performance indicators [21]. KPIs, within the VoC, correspond to the CTQ characteristics, which are a set of indicators with clear targets and specified limits [17]. Yang et al. [25] specified the CTQ-Y as the KPIs of the CTQ. The specifications of the CTQs are the measures of the dependent variable (Y) and the Xs are the key variables or drivers. The factors affecting the CTQ can be represented by the Equation (1).

$$Y = f(X) \tag{1}$$

The current state of the CTQ is specified and the performance measures or key variables (Xs) are searched. In this phase, the potential Xs can be identified through a value stream map (VSM) [21].

VSM is a process flow chart that identifies the added-value and non-value-added activities in a stream product transformation process [5]. The VSM reveals hidden issues in the process, brings options to the surface, and enables the potential to maximise performance by eliminating the waste.

After defining and understanding the process, and having specified and documented the performance measurements, we proceed to the analysis phase. In this phase, the critical factors directly related to the Ys are established. The analyses of the data and process activities allow the detection of the main factors that have an impact on quality from the customer's perspective (value-added) [11].

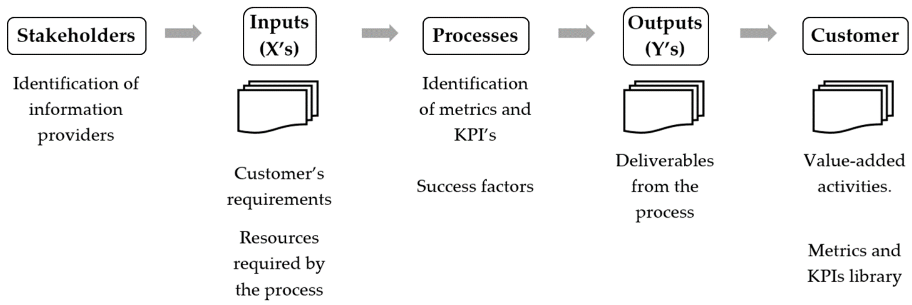

Figure 1. Supplier, input, process, output, customer (SIPOC)—process representation (based on [21]).

3.2.3. Improve and Control Phase

The improve phase is for implementing the proposed methods and improvements [18]. To control and monitor the progress, Cortes et al. [18] recommended the use of a web application (e.g., customised dashboard) in order to access the required standards and project management tools. Since the focus of this paper is on the identification and categorisation of KPIs, the validation, adequacy, and control of KPIs are recommended as future research in the Conclusions section.

3.3. Key Performance Indicators (KPIs)

KPIs are metrics used by some organisations to track the success and guide their progress towards specific strategic objectives. In addition to business strategy, it is important to consider the corporate culture since there is a direct connection between the organizational culture and performance. A solid corporate culture drives the performance and each specific feature impacts the strategy's implementation [26]. Popa [26] highlights that in order to develop KPIs, four main factors must be taken into account. First, ensuring that activities are in line with the objectives; second, collecting the required information to improve the activities; third, controlling and monitoring the activities and the people involved; supporting the reports for the stakeholders.

In a project context, the KPIs are linked to the project success or failure [13]. These indicators have to be measurable and controllable therefore must be quantitative and qualitative [4,13]. All organisations are different and have their own needs and objectives, so KPIs must be tailored to each one; nevertheless, a general framework can be useful as a guide [4]. Kerzner [13] stated that a KPI's most crucial attribute is that it is actionable, meaning that actions can be taken to correct any unfavourable trends.

Within the literature review, several descriptions of KPIs categories were detected. Cortes et al. [18] cite five strategic KPIs categories: Cost, quality, flexibility, stock, and lead time. With these categories, they aimed to capture the company strategic goals and enable the alignment of strategic, tactical, and operational performance. Ogunlana [4] identified several authors that included other performance measurements in addition to the classic iron triangle (time, cost, and quality): Customer satisfaction and overall satisfaction of stakeholders.

Within projects, Kerzner [13] identifies time, cost, resources, scope, quality, and actions as core metrics for project management KPIs. Additionally, Ogunlana [4] delves into performance measurements adding the capacity of the project team to manage project risks and solve problems found in projects in order to evaluate the success of the project. The authors also mentioned other research that suggested measuring project success by the technical performance efficiency of execution, managerial and organisational implications, personal growth, manufacturers' ability, and business performance.

Furthermore, España et al. [1] argues that conventional metrics such as cost, schedule, quality, and security should be used to support the system improvement and not as isolated parameters that request an individual response. The authors explain that evaluating together cost and schedule indicates whether the system is stable or corrective actions are needed, while the cost in conjunction with safety parameters suggest if the work is planned and performed correctly [1].

Ogunlana [4] highlight as future research to focus on the integration of the organisations KPIs with the following aspects: "*operational (time, cost and quality), life cycle (maintenance capacity, energy consumption and user satisfaction), strategic (inter-organisational co-operation, organisational learning) and socio-economic (social and human development)*". Moreover, the authors assured that the criteria for measuring the success of the projects should be based on strategy, sustainability, and safety. Yang et al. [25] describe two categories of KPIs: Financial (e.g., increased sales and decreased material, inventory, and transport costs) and operational (e.g., cycle time, utilisation rate, delivery time, forecast accuracy). All the categorisation mentioned by the authors is summarised on Table 1. These categories are an example of the categories that may be considered within an organisation.

Table 1. Key performance indicators (KPIs) categories list.

KPIs Categories	Indicators	Sources
Financial	Increases in sales	[25]
	Decreases in material	[25]
	Inventory	[25]
	Transportation expenses	[25]
Strategic	Cost	[18]
	Quality	[18]
	Flexibility	[18]
	Stock	[18]
	Inter-organisational cooperation	[4]
	Organisational learning	[4]
Tactic		[18]
Project (operational)	Cycle time	[25]
	Utilisation rate	[25]
	Lead time	[25]
	Forecast accuracy	[25]
	Time	[4]
	Cost	[4]
	Quality	[4]
	Customer satisfaction	[4]
	Overall satisfaction of stakeholders	[4]
	Project team's ability to manage project risks	[4]
	Ability to resolve project problems	[4]
	Efficiency of execution	[4]
	Managerial and organisational implications	[4]
	Personal growth	[4]
	Manufacturer's ability	[4]
	Business performance	[4]
Life cycle	Maintenance capacity	[4]
	Energy consumption	[4]
	User satisfaction	[4]
Safety		[4]
Sustainability (socio-economic aspect)	Social and human development in the area	[4]

Cortes et al. [18] proposed a Lean Six-Sigma framework based on lean indicators for management support during lean implementation intending to lead tactical and operational decisions for performance improvement and maintenance. Lean tools such as the "five whys" and the root cause and effect analysis can be used for establishing performance indicators and for identifying improvement metrics.

The work of Dombrowski et al. [8] proposed specific criteria of a measurement system for performance indicators in product development context. The criteria to be taken into account consists in: Relevance for the enterprise targets, quality data (based on the validity and timeliness of data), compatibility with the hierarchy, variability (react quickly to changes), periodicity, visualisation, and effort. Furthermore, Kerzner [13] describes six fundamental characteristics for project-oriented KPIs: Predictive (future), measurable (quantitative), actionable (changes to correct), relevant (relationship to project success/failure), automated (reports minimise human error), and few in number (those needed). Table 2 shows the characteristics that the KPIs should accomplish according to the literature analysed.

Table 2. KPI characteristics.

	Dombrowski et al. [8]	Iuga et al. [2]	Kerzner [13]	Toor & Ogunlana [4]
Actionable			X	
Automated			X	
Compatibility (hierarchy)	X		X	
Effort	X			
Few in number		X		
Helpful		X		
Measurable			X	X
Objective				X
Periodicity	X			
Predictive			X	
Relevant	X	X	X	
Timeliness	X			
Valid	X	X		
Variability (react quickly to changes)	X			
Visualisation	X			

3.4. Project Success

As has been said, project success as the heart of project management, and the factors that affect it, is a commonly discussed topic in research in project management that has been studied by practitioners and academics since 1960s (it started with the definition of success in terms of the iron triangle, time, cost and quality [27]; and remains relevant to the present day); however, there is not a unified definition [15]. Moreover, we can distinguish two different components: Project success factors: Elements of a project that if influenced, increase the like hood of success (e.g., stakeholder, risk and quality management, etc.) and project success criteria: Measures used to judge on the success or failure of a project (e.g., stakeholder satisfaction, cost, scope, time, etc.) [28].

The first impression of project success is a project implemented among the constraints of time, cost, and quality; however, project success is more than implementing the project within this iron triangle. Constrains and exceeds from those boundaries do not mean that the project was or not successful. Public opinion considers the Sydney Opera House as a successful project, even if it was 14 times over budget and time [29]. Some researchers carried on upon that project and other similar ones led to highlighting two main issues. First of all, the differences in the perception of project success among different stakeholders, and secondly, the fact that project success is beyond controlling the iron triangle constraints and that more dimensions should be considered.

Based on questions like "What factors lead to project management success?" or "What factor lead to a successful project?", Cooke-Davies [30] defined the success criteria (SC) as indicators for measuring the success or failure of the projects, and identified 12 factors that are in one way or another, critical to project success. As well, Lim and Mohamed [28] helped to define the success factors as the set of principles or standards for judgement about the success of a project. Among the top frequently cited on the literature we can identify support from senior management [31], clear and realistic objectives [27,32], strong/detailed plan kept up to date [33], good communication/feedback [30], among others. Top management support was introduced as SF by Müller and Turner [31], and by Pinto and Slevin [27], project ownership [34]. Also, Chan et al. [35] stated that project team commitment, contractor competencies, risk and liability assessment, client competencies, users' needs, and constraints imposed by users are project success factors (PSFs).

There are plenty of studies about the PSFs, each of which represented a wide range of success factors; however, these factors are usually listed or in a very general way or, with such specificity that can only be applied to a particular variety of projects. Nonetheless, in their research, Belassi and Tukel [33] stressed grouping success factors and explain the interaction between them, putting aside the focus from the identification or specificity of such individual factors.

Although varied PSFs are introduced through numerous studies, Cooke-Davies [30] stated that finding the projects' real success factors is important. However, some of this PSFs are extremely important and must exist to ensure the project success; these are called critical success factors (CSFs). In their work, Fortune [36] carried out a review of a series of publications that focused on CSFs, allowing them to identify which were the most frequent success factors mentioned on theoretical or empirical studies and the different stages of the project where these factors were evaluated, letting them conclude that the evaluation of some success factors on different phases of a particular project can help to determine if it is going to be successful or not. Pinto and Slevin [27,32] represented a list of CSFs, including: Technical tasks, client acceptance, power and politics, communication, client consultation, top management support, urgency, environmental events, and characteristics of the project manager, troubleshooting, and personnel recruitment.

As illustrated in Table 3, various factors contribute positively or negatively to project success. Nevertheless, analyses of all success factors are extremely hard. Therefore, some authors grouped the CSFs under "success dimensions", which make the evaluation and interpretation of project success more understandable. Different authors offered different dimensions to be used as criteria to judge project success.

Table 3. Project success dimension.

Project Success Dimension	References
Mission, top management support, schedule, client consultation, personnel, technical, client acceptance, communication, feedback, and trouble-shooting	[27,32]
Communication, time, mission, project management competences, the project delivering the strategic benefits and top management.	[16]
Policy and strategy, mission	[16,30,37]
Project-related, human-related factors, process-related factors, input-related factors, output-related factors	[37]
The future potential of the projects in terms of innovations, generating a new product line or new technological capability	[15,16,38–40]
Project management factors: planning, scheduling, monitoring and control, quality management, and risk management	[27,30,32,38]
Meet stakeholders' expectations, benefit to the stakeholder group, client/customer specific, Client acceptance and consultant.	[16,27,32,38,40,41]
Project efficiency, impact on customers, business and direct success and strategic potential (preparing for the future). Time and costs were considered as resources and quality as customers. Satisfaction in contrast to using them as separate entities	[42]
Goals and objectives, performance monitoring, decision-maker(s), transformations, communication, environment, boundaries, resources, continuity	[36]

4. Defining a Lean-Based KPIs Identification Model

In this study, a model for the identification of KPIs in a project context was developed. For the design of the model, the theoretical concepts previously analysed were used as a basis. Additionally, concepts from success factors and lean models related to performance measurement identified in other studies were considered in the design of the model.

Leading KPIs are established in a way that impacts the most relevant results of the organisation. Although the main indicators vary from one organisation to another, a process based on lean thinking can determine the KPIs of a company. The first step for defining the KPIs is to identify the organisation strategic objectives and the different impacted levels [18]. Cortes et al. [18] proposed a KPI classification, based on the work of Pakdil and Leonard [43], and Gopinath and Freiheit [44], in line with the main lean fundamentals. Roberts and Latorre [45] in their research made a critical analysis of the KPI measurement system. The model proposed is based on selecting the categories from SLR, so the needs identified from the customers (VoC) and the organisational strategies and objectives (VoB) can be set in an organised form. Once that process is completed, the identification of the parameters to be measured as a driver to accomplish the future KPI. Next, the identification of the CTQs gives the information required to raise the performance indicators. Following this, we propose a tie in a measurement to that indicator (e.g., number of, percentage of, amount of, etc.), and finally, the organisation goal must be set. The proposed model to defining and establishing KPIs for projects is resumed in Table 4.

Table 4. Lean-based model for identifying KPIs.

Categories	VoC	Drivers	CTQ	Measurements	Target
Proposed KPIs categories detected in the SLR	Customer's need	Parameters to be measured	The performance indicators	Data at a single point in time, specific, measurable	Organisation's goal
	Organisation's strategies				

5. Case study—CFAA (Advanced Manufacturing Centre for Aeronautics)

Looking for strategies to increase the innovative capacity of universities and thus boost the local economy, the collaboration between companies and universities has been an institutional strategy used to guide ideas, inventions, and innovations generated in universities and transmit them to the industrial and social network [46]. The machine-tool and advanced aeronautical manufacturing sectors have been some of the strategic areas for the economy of the Basque Country in Spain over the last few decades, generating a turnover of up to 3.83 billion Euros [47]. In this context, the creation of a Research, Development, and Innovation (R&D&I) Centre with focus on advanced aeronautical manufacturing technologies that could integrate these two sectors with the University and allow the easy and fast transmission to the industrial production ecosystem associated with the value chain was a fairly straightforward decision [48]. The result was the Centre for Advanced Manufacturing in Aeronautics (CFAA, in Spanish), an open and shared space for researchers, students, and professionals of the sector, companies, and research centres at national and international level, where applied knowledge, technologies and new methodologies for the previously mentioned sectors are being developed.

CFAA was created to operate within the structure of the University of the Basque Country /Euskal Herriko Unibersitatea (UPV/EHU), and emerges from the agreement signed between the UPV/EHU and a group of aeronautical and machine tool companies, and is supported in its origin, constitution, and in the acquisition of facilities and machinery by the Regional Government of Bizkaia and by the Society for Competitive Transformation (SPRI)

The R&D&I projects carried on at CFAA are located between Technology Readiness Level (TRL) 5–7 [49], which guarantee a quick knowledge transfer, and promote mutual benefits to companies and universities from a micro up to a macro-economic point of view, so that universities obtain funding to conduct their research and train staff to enable them responding positively to the demands of the labour market [50]. In addition, it advocates for fostering the relations between companies from different sectors, and in the university–business axis [51,52].

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The role of the CFAA within the projects is, on the one hand, to filter out projects that are in line with their strategy, and from those that result, test their economic, scientific, and technical feasibility in an industrial environment designed and equipped to simulate a real factory. On the other hand, CFAA on its own, and thanks to the interaction of different scientific groups, proposes, develops, and tests advanced manufacturing technologies, techniques, and applied knowledge, born from state-of-the-art research.

CFAA is a project-based organisation, where the success of their projects takes great relevance and a determinant role in the present and future opportunities for the Centre, in the form of being able to participate, or present itself to European calls, taking part in international and specialised clusters, or attracting young and professional talent. However, some studies carried on CFAA had demonstrated that there are still significant improvement opportunities to measure and improve the rate of success in this Centre [53].

To date, almost 300 projects have been carried out with a success rate close to 70%, meaning that the results obtained are being used by the company (or group of companies) that leads the project. This result is thanks to close co-operation between researchers, technicians, University experts, project managers and company staff, collaborating on the prevention of wrong pathways taken at early stages of the project.

Since its inception, CFAA has been committed to boosting scientific activity and contributing to various scientific publications e.g., journals with different impact rates, conferences, book chapters, etc. From 2017, the impact of the CFAA and its manufacturing groups is reflected on more than 140 scientific publications (March 2020) which have generated more than 840 citations. Also, 11 doctoral theses have been developed. Currently, CFAA is working on the implementation of a project management methodology developed ad hoc for the Centre, whose objective is to manage projects, programmes, and portfolios, and push the organisation towards more agility and efficiency [54].

Despite the good state of the CFAA regarding its scientific production, use of resources, collaboration with institutions, and participation in co-operation projects at European level, several of the general objectives set for the Centre [55] and those described in the Centre's Quality Manual, are not being adequately studied, described, and measured.

To date, a few quantifications of consumed hours in projects, number of projects developed, and hours spend using the resources of the CFAA, are being measured (Figure 2). Leaving room for a new set of KPIs oriented to measure the performance of organisational and production needs.

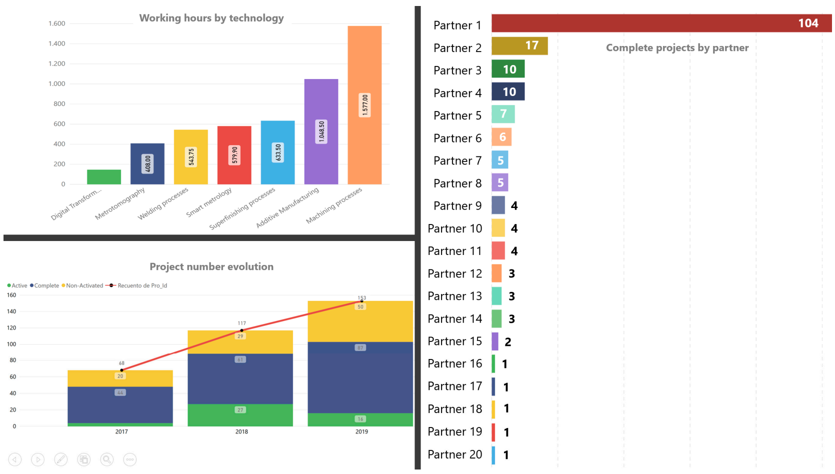

Figure 2. Performance information Centre for Advanced Manufacturing in Aeronautics (CFAA).

6. Applying the Lean-Based KPIs Identification to the Case Study

Burimova et al. [56] carried on a study in order to obtain a clear picture of what "Success" means for CFAA and their most important stakeholders. The study was constructed following one of the most critical remarks behind project success, which is that the success of the project depends on which area (or dimension) is inspected, therefore these areas need to be addressed individually, including not just the business side, but also people management. Consequently, it is crucial to define and evaluate the success criteria at different dimensions. For that study, the success dimensions chosen were:

- ***Project Management Success Dimensions (PMSD):*** Focus on the aspects that are necessary for the right management of the project, e.g., control of time, cost and scope, compliance of quality standards, resources and stakeholder's management, etc.
- ***Delivery Activities Success Dimensions*** **(*DASD*)**: Focus on the processes that are used to create the deliverables.
- ***Deliverable Success Dimensions (DSD):*** Describing the output of the project, including the success criteria needed to verify that the final result of the project matches the scope.
- ***Operations Success Dimensions (OSD):*** Includes the success criteria needed to verify that the operation ensures that the ongoing process of the project is carried on in an appropriate way.

Once the study was conducted, the resume of the results of the most important success factors can be seen at Table 5.

Table 5. Most important success factors for CFAA and stakeholders.

No.	Success Factors	Success Dimension	References
1	Workplace Safety	OSD	[57]
2	Project goal was achieved	PMSD	[27,32]
3	Customer satisfaction regarding the quality of delivery activities of the specific project	PMSD	[58]
4	Reputation of the organisation has increased	PMSD	[59]
5	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)	DASD	[60]
6	Customer satisfaction regarding the management of the specific project.	PMSD	[61]
7	Customer satisfaction regarding the deliverable.	DSD	[62]
8	Degree to which the deliverable meets its intended purpose.	DSD	[63]
9	Return on Investment of the project	PMSD	[57]
10	Workplace security	OSD	[57]
11	Completed within defined and agreed scope	PMSD	[31,64]
12	Completed within defined and agreed time	PMSD	[31,64]
13	Completed within defined and agreed costs	PMSD	[31,64]

The results have shown that the most important success factors are related to the safety of the workplace, also if the project goal was achieved and how the customer feels about the quality of the different deliverables. These results are quite valuable as an input of the strategic needs that CFAA must necessarily focus on.

The analysis of the organisation strategies and needs were found seeking for CFAA documents with relevant information that may guide the identification of performance indicators, e.g., data from a survey about project success for stakeholders and personnel from the organisation, and a benchmarking with a similar Centre like CFAA. Later, a stakeholder validation was carried out to find out their perception of the performance indicators.

6.1. Ruhrvalley Innovation Cluster

As has been mentioned before, the performance parameters used by centres alike need to be analysed in order to compare and understand the rationalisation of their measurement parameters from a more mature point of view. For this research, "ruhrvalley" was chosen among different innovation centres due to different aspects:

– Region: The companies that conform the ruhrvalley innovation cluster are SMEs focused on small but very advanced niches that some of them, regardless of their size, stand as world markets leaders in their domain.
– Cluster: ruhrvalley was formed to provide wider solutions in areas like eMobility, renewable energy systems, and digital transformation.
– Impacts: The expected impact on solutions for urban mobility and energy systems, and the innovation community in the region, develop a strong innovation profile for universities and development of technology-driven start-ups and SMEs on the region.
– Collaboration: An effective interaction model between leading universities and research centres, scientific and industrial associations, and important players from society and politics [65].

ruhrvalley seeks a combination of applied research, academic education with a strong application focus (high TRL), industry co-operation, and a strong rivet on innovation and entrepreneurship [66], as does CFAA. Sastoque et al. [51] mentioned that CFAA and ruhrvalley have had a strategic matching to increase an impact of R&D results in the scientific community. They also have some contextual factors in common, like their location, due to both of them being placed in industrial urban areas under processes of digital transformation through technology- and innovation-driven approaches. Regarding the TRL, ruhrvalley goes one step further than CFAA, with TRL 6–7 for CFAA and TRL 6–8 for ruhrvalley. Also, they both focus on Industry 4.0 technologies.

6.2. KPIs Construction

In order to assemble the KPIs for CFAA, the classification was made based on the study carried by Wolff and Nuseibah [65] and divided on four different scopes: Innovation, region, research and development, and university. Next, the strategic needs for each one of those scopes were inferred from the information sources previously mentioned Table 6.

Table 6. Strategic needs—CFAA.

Scope	Strategic needs
Innovation	Create and marketing new services, product lines and technological capabilities Institutional support of SMEs with innovation impulses in the development of new business models
Region	CFAA as a place of interest for local and international partners to develop projects. Increase the attractiveness of the Basque Country for research, innovation, employment and start-ups Intensify knowledge transfer Interact with society, strengthen actors and civil society
Research	Gather and generate experience, new knowledge and understanding from activities and management of the project (e.g., tools, techniques, approaches or processes) Increase the impact of R&D in the scientific community
University	Professionalizing project management Promote compliance with the goals and objectives for which CFAA was created. Securing the freedom, financial and personnel basis for research and transfer activities in the long term Strengthen collaboration with University in the implementation and development of projects

At the end of the analysis of the information gathered, besides these 12 strategic needs, 51 operational needs and 56 internal factors (drivers) were also identified. However, for this paper, the result of the study of the strategic and operational needs for the scope of innovation will be shown.

The CTQ started by identifying the critical Xs for the first strategic need (Y): Creating and marketing new services, product lines, and technological capabilities. Next, the specific measurements required to fulfil the quality requirements were previously identified. A target value for each of the measurements must be set according to the organisation expectations (Table 7; Table 8).

Table 7. Strategic need: Creating and marketing new services, product lines, and technological capabilities (Y).

Operational Need	Category	Drivers	CTQ	Measurements	Targets
Contribute to sustainability in the creation, design and result of deliverables from the projects	Sustainability	Strengthen strategic human resources development as a research priority	Watch over the rights and interests of the workers.	Number of complaints received vs. attended.	100% complaints received vs. attended.
				Number of wellbeing activities programmed vs. realised	100% wellbeing activities programmed vs. realised At least one well-being activity programmed vs. realised
				Number of Safety programme activities programmed vs. realised	100% of Safety programme activities programmed vs. realised 85% of participation from personnel at Safety programme activities programmed vs. realised
	Sustainability	Sustainability through creation, design and result of deliverables from the projects	Avoidance of waste	Number of good practices implemented in the use of waste	100% compliance with good practices implemented in the use of waste
			Hazard materials treatments	Kg per type of hazard materials treated	100% of hazard materials treated
				Notices received by the authority for mismanagement of hazards	Cero notices received by the authority for mismanagement of hazards
			Safety and security initiatives to avoid accidents or incidents	Number of safety programme activities programmed vs. realised	100% of safety programme activities programmed vs. realised
				Number of security programme activities programmed vs. realised	100% of security programme activities programmed vs. realised
				Number of safety events	At least 5 safety events programmed per year
				Number of security events	At least 5 security events programmed per year
Develop and implement marketing of the R&D service portfolio	Technical	Marketing of R&D and innovation service portfolio	Marketing campaigns of R&D and innovation service portfolio	Marketing campaigns of R&D and innovation per innovation	At least one marketing campaigns of R&D and innovation per innovation
Generate new usable knowledge and engineering solutions	Operational	Usable knowledge and engineering solutions generated	New methods vs. solutions published in scientific journal	Number of new methods vs. solutions published in refereed journals.	At least 3 publication by each new methods vs. solutions produced at CFAA.
				Number of new methods vs. solutions presented at refereed conferences	At least 3 attendances by each new methods vs. solutions produced at CFAA
			New patents	Number of new patents registered	100% of new patents registered
				Number of articles published in refereed journals regarding uses of patents.	At least 3 articles published in refereed journals.
				Number of presentations at refereed conferences regarding use of patents.	At least 3 presentations at refereed conferences.
				Number of marketing campaigns per patent	At least one marketing campaigns per patent.
Increase demand orientation in transfer	Strategic	Transfer-oriented demand	R&D strategy workshop participations vs. Organized	Number of participations at R&D or innovation workshops	85% of participations at R&D or innovation workshops
			Innovative activities developed	Number of R&D or innovation workshop organised	At least one R&D or innovation workshop organised by CFAA
Introduce continuous innovation management	Technical	Continuous innovation management introduction	Innovation projects developed	Number of projects developed characterised as "Innovative" from partners	Success rate > 80% of projects developed characterised as "Innovative" from partners
				Number of projects developed characterised as "innovative" from CFAA	Success rate > 80% of projects developed characterised as "innovative" from CFAA

Table 8. Strategic need: Institutional support of SMEs with innovation impulses in the development of new business models (Y).

Operational Needs	Category	Driver	CTQ	Measurements	Targets
Enable and encourage talent early on	Technical	Formation to encourage innovation skills	Formation to develop innovation skills	Number of courses related//needed to encourage innovation skills	At least 2 courses per year
		Students at CFAA doing their TFM or TFG	Students participation at CFAA	Number of new students doing TFM or TFG	At least 30 students per year
		Students at CFAA doing On-the-job formation	Students at On-the-job formation at CFAA	Number of new students doing On-the-job formation	At least 10 students per year
Expand existing cooperation into strategic innovation partnerships	Strategic	Cooperation in strategic innovation partnerships	Partner participation in projects	% of Partners participation in projects	70% of partners participating in at least one project per year
			Effective cooperation development plan	Plan's implementation	30% of partners involved in the plan
			Framework agreement with all partners	Partners involved in the Framework agreement	30% of partners involved in the plan
Promote the foundation, establishment and accompaniment of spin-offs	Technical	Foundation, establishment and accompaniment of spin-offs	Spin-offs from CFAA	Number of new spin-offs from CFAA	At least 1 initiative per year
		Foundation, establishment and accompaniment of spin-offs	Initiatives enabled and encouraged	Initiatives enabled and encouraged	At least 1 initiative per year
		Business start-ups provoked	Start-ups projects activated	Number of recruitments of innovative start-ups and joint ventures	At least 1 initiative per year
			Coordination and cooperation with start-up support entities (Universities, governments, private investors)	Number of new cooperation agreements with associations and business development agencies	At least 3 agreements signed per year

7. Conclusions and Future Research

Lean thinking can lead to knowing an organisation in a deeper way, asking questions that were overlooked, and reaching conclusions of highly strategic value for the company. In this research, through an SLR, the literature on the process of KPI definition was analysed through a lean approach in project-based organisations.

Through the concepts gathered in the SLR, a classification of KPIs was identified, and a lean-based model was developed to define the KPIs. This model was applied to a case study conducted within a R&D project-based organisation (CFAA). Following a series of steps based on lean tools and principles, the model worked as a guide for the identification of KPIs. The DMAIC methodology phases were used in order to keep an organised process flow for the model implementation.

The first step was to establish the current status of the company as well as explore the stakeholders needs and requirements with the VoC. To complement the initial information and to determine the strategic needs (VoB), the company quality manual was reviewed. The literature highlights the importance of KPI formulation based on strategic business objectives as well as corporate culture. Although this is the starting point towards the identification of performance indicators, the scope of this research does not include the analysis of corporate strategy and culture. Furthermore, it was considered useful to benchmark with a similar leading organisation (ruhrvalley) in order to get baseline performance indicators. After obtaining the data to define the CTQs, we proceeded to measure and analyse the internal factors, measurements, targets, and performance indicators that constitute the KPIs.

The result was a series of qualitative and quantitative KPIs that evaluates the strategic and operational needs of a project-based organisation and helps to understand and improve their performance criteria. However, those defined KPIs cannot be unmovable. The continuous changes in the market or the research methodologies require KPIs to be constantly redefined and updated, in order to ensure that KPIs are suitable for the current environment of the organisation [18].

The scope of this research was limited to proposing a model for the identification of KPIs using the lean approach, therefore for future research, it is suggested to continue with the following actions of validating, communicating, reporting, and controlling the adequacy of the KPIs. "Visual management" is a suitable technique to manage the quality of the KPIs [2]. For managers and project managers, the use of KPIs "dashboards" are recommended during to report, monitor, and control the KPIs [11].

As a next step, a project plan must be developed to ensure the right applicability of the KPIs at CFAA and a system to measure their effectiveness in the organisation. Additionally, the integration of the information coming from different areas of the organisation (IoTs, edge computing devices, project reports, etc.) to ensure the correct functioning of the KPIs should be assured. It is a process as important as the formulation of the KPIs itself, for the use of dashboards, scorecards, and reports that show information almost in real time is highly recommended.

The result of this research is of high value for project-based organisations, especially those new ones that are not apprised of how to correctly formulate a series of KPIs, or whose path is still not clear.

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9

Project Management methodology for R&D projects.

The final objective of the thesis was to develop a methodology for managing R&D projects using quality criteria as a performance indicator. The development of this methodology is embedded in the technology transfer TRLs 5 - 7, understanding the best practices and strategies to strengthen the collaboration between University and Industry, but at the same time, based on the study of the success criteria for R&D projects and the KPIs of the organisation.

A first approach was carried out in which an ad hoc project management methodology was developed for the CFAA (project-based organisation), which was developed based on agile methodologies principles and the lean Kanban method.

A second exercise was conducted in which, through the analysis of data from past projects in a project-based organisation, a study on the use of quality criteria as a measure of project performance, and the study of hybrid project management methodologies, a methodology was developed for the management of R&D projects in which project performance was measured through quality criteria.

The results of this research are included in the following publications.

9.1 CP. 4 - Conference Paper.

Farokhad, M. R., Pinilla, E. L. S., Toledo, N., Gandarias, L. N. L. D. L., & Olaso, J. R. O. (2019). Hybrid Project Management Methodology for R&D, Innovation and R&D&I Projects in CFAA. In Dortmund International Research Conference 2019 (p. 77) [9].

HYBRID PROJECT MANAGEMENT METHODOLOGY FOR R&D, INNOVATION AND R&D&I PROJECTS IN CFAA

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Abstract: *The aim of this research is to investigate about a project management methodology which fits to CFAA (a research center created by a public-private initiative in the Basque Country) in which different types of innovation, R&D and R&D&I projects are implemented. Authors seek to create a project management methodology to be customized for this Center to manage projects, programs and portfolios, and push the organization toward more agility and efficiency. The research methodology is based on descriptive study, reviewing of different resources such as books, articles, journals as well as interviews to determine the appropriate project management methodology to be implemented in this Center.*

Keywords: R&D project management approach, Innovation project management approach, R&D&I project management methodology, TRL 5 – 7.

1. Introduction

The Advanced Manufacturing Center in Aeronautics (CFAA in Spanish) was created with the aim of developing advanced manufacturing technologies located between the Technology Readiness Level 5 to 7 [1]. The CFAA was inaugurated in 2017 in the Technological Park of Biscay, also conceived by a conjunction of the University of the Basque Country (UPV/EHU) and the Business Cluster for the Development of Advanced Aeronautics Manufacturing Techniques. Together with the Basque Country Government and Provincial Council of Biscay, in collaboration with the Technological and Scientific Park of Biscay, enables the Center to focus on the end applications of aeronautics production, without forgetting the generation, use and fine-tuning of new knowledge in advanced manufacturing techniques.
Nowadays, the CFAA is formed by 76 partners, has had a total budget of about 2 million euros since his foundation, which has allowed to complete several projects in the different areas identified as vitals for the partners, government and university. 25 people are within the staff of researchers, 8 of them are doing their PhD and 7 of them are responsible for the project's coordination and research. It has also 8 professors from the University who share their time in the Center's research. There are also 20 people from partner companies working in the Center and 7 more are in dual training for partner companies.
This Center acts as an intersection of ideas and advancement for agencies and companies with capabilities and interests in the aeronautical engines and structural components sector, developing R&D, innovation, and R&D&I projects, which are complex projects with high level of uncertainty and risks [2].

1.1. The importance of project management

Implementing a project management methodology carry out great improvements on the KPIs of a company. The Centre for Business Practices (CBP) reported 75% improve in employee's productivity; besides 27% improvement in return on investment (ROI) and 30% improvement in budget performance as well as 50% more projects completed. Customer satisfaction increased about 38%, as a result of implementation of project management methodologies. Moreover, project management not only has positive impact on the organization, but also on the employees' satisfaction by increasing employees' satisfaction 40% CBP, also Thomas and Mullaly [3] reported 58% improvement in employees' quality of life.

Although there is a wide range of projects in CFAA, the lack of comprehensive and customized project management methodology is noticed. In order to clarify the importance of project management, this research review the statistical reports regarding projects' success rate through implementation of project management. Considering the statistical reports regarding the projects' success rate directed the authors to concern about conceptualizing the customized project management methodology for CFAA. To achieve this goal, firstly the identification of the current situation of the projects in CFAA is essential.

1.2. Project management in CFAA

The activity of the CFAA is centered around the planning and realization of projects included in a List of Projects (LOP), in which the intensive use of the resources is sought in fulfillment of the aims of the Centre. This LOP is prepared on the basis of the proposals made by each of the members of the Centre, sent for study and acceptance during a period of the year by a Technical Committee. The duration of the project depends on the planning that is done between the partner project's lead and the Centre, taking into account the disposition of its resources, which is established according to the order of arrival of the requests, followed by the hierarchy of the partners.

Table 1. CFAA Partners summary (2019), classification by type and industry

Type	Industry	Quantity
A	Large size machine tools	1
	Tier 1 Aeroengines	1
B	Cutting-tool Medium size companies	3
	Machine-tools Medium size companies	1
	Metrology companies	2
	Metrology and Additive manufacturing	1
	Machine-tool Small size manufacturers	1
C	Additive m.– machine developers	1
	Cutting tools and accessories	1
	Digital Transformation	1
	Engineering services	1
	Tier 2 Aeroengines	2
	University	1
	Welding equipment and consumables	2
	Work holding	2
D	Additive manufacturing – services	1
	Cutting tools and accessories	31
	Digital Transformation	5
	Engineering services	4
	Technology providers	1
	Work holding and fixtures	5
SC	Digital Transformation	1
	Engineering services	4
	Industrial Clusters: a) machine tools and b) aeronautics	2

Metrology equipment	1

During those three years of operation, the existing control mechanism for the project management in the Centre was the LOP, which produce that the planning of activities and scheduling the use of machines and human resources, depended entirely on this file. This way of managing was adopted because of the need to control the activities that were carried out in the Center; however, no project management methodology had been considered for its subsequent implementation and daily use. Likewise, a large percentage of the projects that had been approved in the LOP are pending (Table 2), either due to the lack of information from the Partner (principal interested in the realization of the project) or the lack of resources for its realization. The absence of the proper information necessary for the realization of these projects such as resources needed, time foreseen, main tasks, stakeholder analysis and even the objective of project is experienced, which increase the difficulty of projects' realization for the project's coordinators of the Centre.

Table 2. Projects resume - CFAA

Year	Complete	Pending
2017	69.12%	30.88%
2018	74.36%	25.64%
2019	42.16%	57.84%

1.3. Innovation projects and R&D projects characteristics

CFAA projects are mostly innovation, R&D and sometimes R&D&I projects. In order to manage these projects, it is essential to examine about the characteristics and identification of such projects. Mikulskiene [2] stated that R&D projects are complex projects with high level of uncertainty and high risks, including highly intelligent activities, which are associated with barriers, dramatic collaboration change, breakthroughs and the quality is judged by experts; furthermore, the goal for R&D projects is "ambitious", "optimistic", and "challenging; therefore, Stuckenbruck [4] stated that renewing the goals and rethinking of ideas as well as changing the methods happens during R&D project; besides Energy Facility Contractors Group [5] described the progressive scope of R&D projects, which can be reached to the stable situation through iterative researches.

Since R&D projects don't have defined-goals, process and detailed planning in initiation phases are not possible, producing that the managing of such projects a not easy task. Mikulskiene [2] mentioned that there are a lot of issues in managing R&D projects related to planning, resource allocation and scheduling since R&D project should have flexible planning to cope with new methods and changes.

Furthermore, in CFAA are innovation projects, which in turn have the non-linear process [6] and are associated with remarkable challenges such as the possibility of failure, the high rate of ending up projects without any results, the variable project scope, the long-lasting project life cycle, the conflict between researchers' interest and companies' interest, difficulty of bounding innovation projects to defined time periods and planning, and not-fixed scope of innovation projects which is changing due to internal and external factors [7].

2. R&D project management and innovation project management approaches

To manage innovation and R&D projects, Mikulskiene [2] referred to tow-stage R&D project management. The first phase, planning, is more technical rather than the second step which is associated with human resource issues, stakeholders, partners and team.

Stuckenbruck [4] represent four-phased project management life cycle, which is a linear approach that includes project concept, project planning, project implementation and project completion. Setting up abstract goals, having flexible planning, focusing on constrains and the

environment is recommended in this methodology. Kerzner [8] represented a five-phased of project life cycle to develop new products including: conceptual, planning, testing, implementation and closure phases. Overlapping phases and break down a long-lasting product development project into smaller projects are specifications of this approach.
Six-phased life cycle as the best R&D project is also in alignment with above-mentioned approaches. Although four-phased, five-phased and six-phased life cycle is defined in different phases with detailed information, the appropriateness of them are under question, since these approaches have linear structure; while R&D happens in non-linear phases [9].
Reviewing the literature on R&D project management clarify the need for non-linear structure for going back to general idea and detailed planning at the beginning of projects is inevitable due to the characteristics of R&D projects. To summarize, although phased-life cycle approaches are needed to clarify the whole process of R&D project management, the non-linear approach should be defined to provide the chance for more creativity, flexibility and changes in general ideas, primary planning and used methods and technologies, in addition, the need for iterative and incremental research phase are essential to overcome the progressive scope and narrow the changes.
To manage innovation projects, different methods has been discussed. Phased project planning (PPP) is a control mechanism for New Product Development (NPD), introduced by NASA to guarantee that the NPD projects will be implemented according to the plan and delivered on time. However, the engineering driven PPP approach was too time consuming and too bureaucratic [10]. To cope with the limitation of PPP approach, Cooper [11] introduced stage-gate system approach, which is a quality-focused framework that contains different stages, each one has its own inputs and deliverables which are assessed, checked and approved before continuing to the next stages. Although stag-gate approach considered the business case and focused on the market, this approach does not provide the opportunity for creativity and innovation as a result, a hybrid methodology is suggested to mix the agile methodologies and traditional methods.

3. Hybrid approaches in innovation project management and R&D project management

Gutiérrez et al [12] developed a new R&D project management methodology for NPD, he combined the classical project management theory and some of the best practices in the scrum. This methodology includes definition, design, development, testing and release phases. Is also associated with several benefits such as quick feedbacks from customer sides derived from a scrum approach in development phase and controlling all aspects happens in release phase, in addition saving money and time through redesign cycles and testing the usability and functionality of the deliverables during sprints in development phases. Figure 1 represents this methodology.

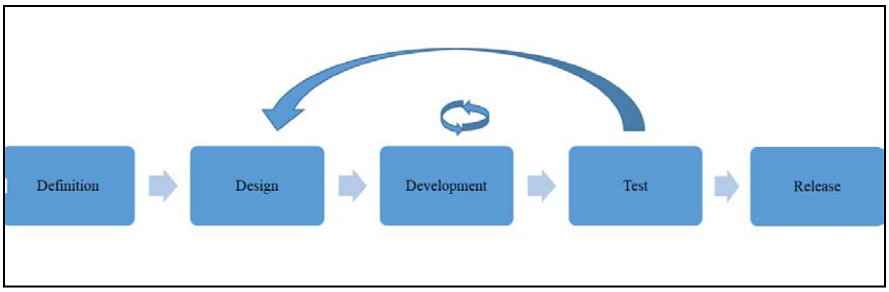

Figure 1. R&D project management methodology [12]

Cooper [13] represented the triple A approach which is a hybrid structure of Stage-Gate and agile approach. Triple A stands for adaptive & flexible, agile, and accelerated. Adaptive comes from the team adaptation to the context of the project, and agility happens during iterations and spirals.
Perez and Louw [14] represented Fugle Innovation approach, which is the combination of stage-gate approach with the agile approach. This approach relay on innovation process and carried out internally, but connected with the external environment and out sourcing, overlapping stages and iterative loops are the possibilities of this approach. This is also applicable in both product manufacturing and service providers and rely on innovation including the whole innovation process.
Sommer et al. [15], introduced the industrial scrum, which is the combination of stage-gate approach and scrum. In this approach, the organizational level applies the stage gate approach, while the project level used the scrum.
However, still one question exists that how decision making over combining two approaches happens. Fijn [16] represented a positioning model through that decision making over combining approaches is facilitated. In this model, the linear structure and the level of control over the environment are main axes for decision making. To manage projects with linear structure in dynamic environment triple A approach is suggested, while for non-linear structural projects, the combination of stage-gate and agile approaches should be applied. Figure 2 shows Fijn positioning project management approaches.

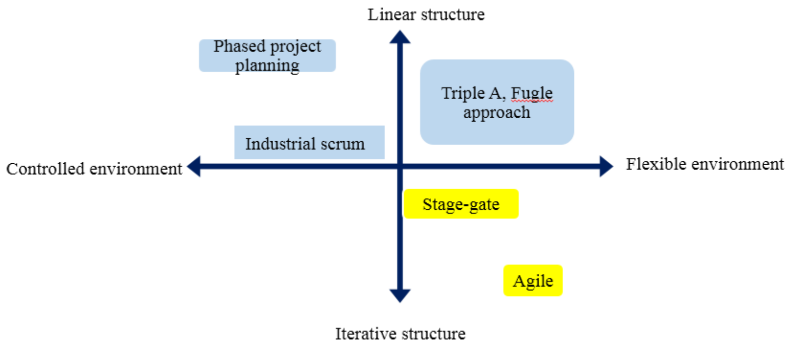

Figure 2. Fijin positioning project management approaches [16]

4. Hybrid project management methodology for R&D, innovation and R&D&I projects in the CFAA

Taking into consideration the characteristics of R&D projects and innovative projects as projects with ambitious goals, not fully defined methods and non-linear process, directs the authors to create a nonlinear and hybrid methodology for managing the R&D&I projects. The bases of the methodology are summarized as below:
According to the Fijn [16] positioning project management approaches figure (2), the suggested hybrid methodology will be a combination of stage-gate and agile approach since the identity of the projects are mainly R&D and/or innovative projects, which have the non-linear process and implemented in a non-controllable environment. Taking into consideration the tow-stage R&D project management [2], four-phased project management life cycle [4] and five-phased of project life cycle [8], the authors come to the conclusion that phased-life cycle approaches are needed to clarify the whole process of R&D project management. In addition, based on Energy Facility Contractors Group [5], the need for iterative and incremental research phase are essential to overcome the progressive scope and narrow the changes.

Furthermore, deep investigation based on stage-gate system approach of Cooper [11] which is a quality focused framework leads to proposing the model consists of 6 phases, which each phase has its own inputs and deliverables and they are assessed, checked and approved before continuing to the next stages. Also, due to the fact that CFAA is involved in NDP projects and the new practical R&D project management methodology for new product development of Gutiérrez et al [12] in Figure 1, was an approved practical example for hybrid R&D project management methodology applied in the automotive industry and assumed as a role model in our investigation.

Table 3. Classification of projects CFAA – R&D&I

Type of projects	Percentage
Creation or development of new product technology platform	8.31%
Innovation	3.99%
Product or technology enhancement	46.84%
Project oriented to new product or process	40.86%

Reviewing the existing information and realizing interviews with the project coordinators and experts in CFAA, they provide some information about the fact that in CFAA there are innovative projects (Table 3), which in turn have the non-linear process, then, according to the Leydesdorff et al [6] the non-linear approach should be defined to provide the chance for more creativity, flexibility and changes in general ideas, primary planning and used methods and technologies as a result the backward steps are defined in this model.
Reviewing the literature surrounding hybrid approaches grabbed our attention over the fact that, the scrum approach cannot be completely applicable in this Centre since there are not remarkable software and IT projects in this centre, besides, although the iteration and increments are needed in each phase, the time constrains cannot be considered for them. Figure 3 illustrate the methodology.

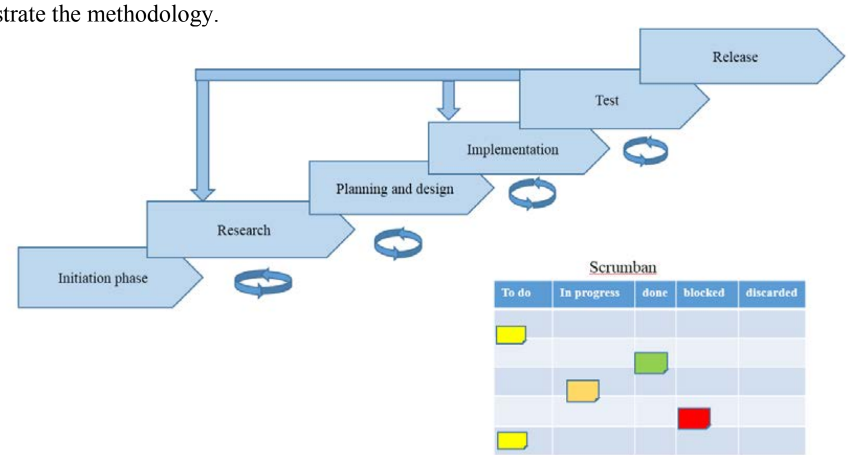

Figure 3. R&D&I project management methodology

4.1 Initiation phase

During this phase, a project is originated from the generation of an idea, and based on that, some requirements (duration, resources, budget, and initial scope) must be defined. An initial planning and project charter are recommended activities to do during this phase.

4.1. Research

This phase is applicable through (not time-boxed) iterations and spirals to do feasibility studies regarding the determination of methods, applicable technologies, tools and knowledge as well as narrowing the scope of the projects to reach the project scope baseline. Once it is done, a better perspective of the initial scope (it can be change in this phase), and the duration, resources and budget needed to do so, must be achieve.

4.2. Planning and design

The scope baseline and the results of the research will be used as an input for detailed planning of the project and design, if it is needed. Design and prototyping can be done through iterations and the final results should be presented or reported to the partners.

4.3. Implementation

During this phase, the activities planned must be done. To do so, can be used a Scrumban board to illustrate the status of the activities (to be done, in progress, done, blocked or discarded). Also, its recommended that the stand-up meetings in front of the scrumboard for issue tracking and problem solving to be done.

4.4. Test

Test and measuring the results as well as quality control happens in this stage. If the deliverables do not meet the desired results (defined in Phase 3), iterations provide the chance for more tests, also backward to design and implementation is possible.

4.5. Release

This phase consists on activities such as installation, delivery, reporting and final representation for partners, documentation and lesson learned meeting and evaluation.

5. Conclusion

The proposed project management methodology has several characteristics which seem to fit for R&D, innovation as well as R&D&I projects. In fact, the stages and phases of this methodology guarantee the control and monitoring ability, while the iterations and spirals which derived from the agile approach provide the chance for flexibility, learning and responding to the flexible environment. Besides, iterations in research phase are essential to narrow the changes of progressive scope and finally reach the scope baseline. In addition, overlapping stages increase the fluidity and the possibility to have parallel activities.

This methodology paves the way for going back toward applied-methods to edit and modify them according to the feedbacks received from the main stakeholders. Furthermore, application of Scrumban board in the implementation phase is a proper communication tool that illustrates the status of the activities (to be done, in progress, done) as well as the blocked or discarded activities, which decrease the efficiency of the projects. Stand-up meeting during the implementation phase is strongly suggested especially for the problem solving and accelerating the speed of the work in progress. The last but not least, knowledge storage and sharing in release phase provide the chance for similar projects in the future to use the knowledge.

This methodology has been extended and been approved to be used in the CFAA by the project managers in the Centre. The project coordinators will apply this methodology in several projects to evaluate the usability of the proposed project management methodology. This methodology is a main component from a whole system of project management that will be implemented in the CFAA during the second semester of the year.

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9.2 JP. 4 - Original Journal Paper (In process).

10

Communications and other Publications.

10.1 Press Communications.

1. **AIMS, cooperación para impulsar la inteligencia artificial en la fabricación industrial** (In English: AIMS, cooperation to boost artificial intelligence in industrial manufacturing).
   - https://tinyurl.com/49pa7zp2 - Last Access: 20/12/2022

2. **Tesis doctorales: Y dicen que no se implican con la industria** (In English: Doctoral theses: and they say they don't engage with industry).
   - https://tinyurl.com/3vfuv89r - Last Access: 20/12/2022

3. **Gestión inteligente de proyectos: optimización de recursos del esfuerzo común** (In English: Smart project management: optimising the resources of the common effort).
   - https://tinyurl.com/2wmwtytw - Last Access: 20/12/2022

4. **Hay datos, pero ¿qué hacemos con ellos?** (In English: There is data, but what do we do with it?).
   - https://tinyurl.com/2xdsb233 - Last Access: 20/12/2022

5. **Digitalización al servicio de la fabricación. Un nuevo reto para el Centro de Fabricación Avanzada Aeronáutica CFAA** (In English: Digitalisation at the service of manufacturing. A new challenge for the Centre for Advanced Aeronautical Manufacturing CFAA).
   - https://tinyurl.com/4w3rbtc9 - Last Access: 20/12/2022

6. **El 4.0 toma vuelo en el CFAA** (In English: 4.0 takes off at the CFAA).
   - https://tinyurl.com/mr3vuv75 - Last Access: 20/12/2022

10.2 Other publications.

- **Original Journal Paper.**
  1. Rodríguez, A., Fernández, A., López de Lacalle, L. N., & Sastoque Pinilla, L. (2018). **Flexible abrasive tools for the deburring and finishing of holes in superalloys.** Journal of Manufacturing and Materials Processing, 2(4), 82 [159].

  2. Escudero, G. G., González, H., Calleja, A., Pinilla, L. S., & Rementeria, I. A. (2020). **Tecnologías clave para la nueva fábrica inteligente.** Eurofach electronica: Actualidad y tecnología de la industria electrónica, (475), 28-36 [160].

  3. López de Lacalle, L. N., Fernández Valdivielso, A., Amigo, F. J., & Sastoque, L. (2020). **Milling with ceramic inserts of austempered ductile iron (ADI): process conditions and performance.** The International Journal of Advanced Manufacturing Technology, 110(3), 899-907 [161].

  4. Del Olmo, A., de Lacalle, L. L., de Pissón, G. M., Pérez-Salinas, C., Ealo, J. A., Sastoque, L., & Fernandes, M. H. (2022). **Tool wear monitoring of high-speed broaching process with carbide tools to reduce production errors.** Mechanical Systems and Signal Processing, 172, 109003 [13].

- **Conference Paper.**
  1. Del Olmo, A., de Pissón, G. M., Sastoque, L., Fernández, A., Calleja, A., & De Lacalle, L. L. (2021, October). **Merging complex information in high-speed broaching operations in order to obtain a robust machining process.** In IOP Conference Series: Materials Science and Engineering (Vol. 1193, No. 1, p. 012079). IOP Publishing [162].

  2. Sastoque-Pinilla, L., Mikhridinova, N., Ngereja, B. J., Wolff, C., & Toledo Gandarias, N. (2022). **Knowledge Discovery Process Applied to Building Competence Profiles Description.** In Dortmund International Research Conference 2022 Proceedings. Fachhochschule Dortmund; Dortmund [145].

  3. Mikhridinova, N., Ngereja, B. J., Sastoque Pinilla, L., Wolff, C., & Van Petegem, W. (2022). **Developing and improving competence profiles of project teams in engineering education.** In SEFI Annual Conference [163].

11

Data Appendix.

11.1 CFAA's KPIs.

1. Scope - 1.1. Strategical Need - 1.1.1. Operational Need / Category	Financial	Life cycle	Operational	Project	Strategic	Sustainability	Technical	Total
1. Innovation	—	—	7	—	5	12	10	34
1.1. Creating and marketing new services, product lines, and technological capabilities.	—	—	7	—	2	12	3	24
1.1.1. Contribute to sustainability in the creation, design and result of deliverables from the projects	—	—	—	—	—	12	—	12
1.1.2. Develop and implement marketing of the R&D service portfolio	—	—	—	—	—	—	1	1
1.1.3. Generate new usable knowledge and engineering solutions	—	—	7	—	—	—	—	7
1.1.4. Increase demand orientation in transfer	—	—	—	—	2	—	—	2
1.1.5. Introduce continuous innovation management	—	—	—	—	—	—	2	2
1.2. Institutional support of SMEs with innovation impulses in developing new business models.	—	—	—	—	3	—	7	10
1.2.1. Enable and encourage talent early on	—	—	—	—	—	—	3	3
1.2.2. Expand existing cooperation into strategic innovation partnerships	—	—	—	—	3	—	—	3
1.2.3. Promote the foundation, establishment and accompaniment of spin-offs	—	—	—	—	—	—	4	4
2. Region	6	—	5	5	18	—	4	38

2.1. CFAA is a place of interest for local and international partners to develop projects.	6	—	4	5	3	—	1	19
2.1.1 Assure by any possible means that the project's results are helpful for the project partner	—	—	2	—	—	—	—	2
2.1.2 Assure fluid communication with the partner before, during and after the development of the project	—	—	—	—	2	—	1	3
2.1.4 Find partners eager to share and collaborate with knowledge, commercial and technical interests.	—	—	—	—	1	—	—	1
2.1.5 Increase the reputation of PMO	—	—	—	5	—	—	—	5
2.1.6 Increase the return of investment of the projects	6	—	—	—	—	—	—	6
2.1.7 Increasing awareness of CFAA as a centre of excellence	—	—	1	—	—	—	—	1
2.1.8 Project development according to the partners' expectations	—	—	1	—	—	—	—	1
2.2. Increase the attractiveness of the Basque Country for research, innovation, employment and start-ups	—	—	—	—	9	—	—	9
2.2.1 Contribute to the creation of wealth in the Basque Country, supporting and promoting sustainable competitiveness of Basque Country Companies	—	—	—	—	4	—	—	4
2.2.2 Involve local companies of strategical sectors in R&D projects	—	—	—	—	1	—	—	1

2.2.3 Promote the internationalisation and technological innovation of partners companies	—	—	—	—	4	—	—	4
2.3. Intensify knowledge transfer	—	—	1	—	6	—	—	7
2.3.1 Contribute to the advancement of knowledge and social development through R&D and innovation	—	—	—	—	4	—	—	4
2.3.2 Increase graduate retention in SMEs in the region	—	—	—	—	1	—	—	1
2.3.3 Involve personnel from partner companies as active actors in the implementation and development of projects	—	—	1	—	—	—	—	1
2.3.4 Promote and coordinate the technology transfer of R&D and Innovation activities	—	—	—	—	1	—	—	1
2.4. Interact with society, strengthen actors and civil society	—	—	—	—	—	—	3	3
2.4.1 Presence at popular science events	—	—	—	—	—	—	1	1
2.4.2 Presence in regional and national press	—	—	—	—	—	—	1	1
2.4.3 Presence on relevant portals and social media	—	—	—	—	—	—	1	1
3. Research	—	—	—	—	6	—	4	10

3.1. Gather and generate experience, new knowledge and understanding from activities and management of the project (e.g. tools, techniques, approaches or processes)	—	—	—	—	4	—	2	6
3.1.1 Develop, test, establish and transfer theory and methodology.	—	—	—	—	4	—	—	4
3.1.2 Issuing central reference publications	—	—	—	—	—	—	2	2
3.2. Increase the impact of R&D in the scientific community	—	—	—	—	2	—	2	4
3.2.1 Increase publication output and conference attendances	—	—	—	—	—	—	1	1
3.2.2 Initiation of joint projects with renowned research partners	—	—	—	—	2	—	—	2
3.2.3 Scientific publications from project results in refereed journals	—	—	—	—	—	—	1	1
4. University	1	5	2	6	12	—	16	42
4.1. Professionalizing project management	—	—	—	6	3	—	1	10
4.1.1 Implement troubleshooting methods and process	—	—	—	—	—	—	1	1
4.1.2 Performance monitoring and evaluation of projects development and results	—	—	—	5	—	—	—	5
4.1.3 Risk evaluation of realised opportunities (known unknowns) and suffered threats	—	—	—	1	—	—	—	1

4.1.4 Set up strategic and operational multi-project management	—	—	—	—	3	—	—	3
4.2. Promote compliance with the goals and objectives for which CFAA was created.	1	—	—	—	1	—	10	12
4.2.1 Ensure the financial, scientific and international success of the CFAA and the continuity of the activities	1	—	—	—	—	—	7	8
4.2.2 Meet the technical and management objectives of the Centre	—	—	—	—	—	—	2	2
4.2.3 Strategic potential of the projects developed	—	—	—	—	1	—	—	1
4.2.4 Top management support to assist the compliment of the mission, policies and strategies of CFAA	—	—	—	—	—	—	1	1
4.3. Securing the freedom, financial and personnel basis for research and transfer activities in the long term	—	5	1	—	3	—	5	14
4.3.1 Creating scope for research	—	—	—	—	2	—	4	6
4.3.2 Detect, analyse and resolve non conformities at time	—	2	—	—	—	—	—	2
4.3.3 Keep the technical capacities needed for the project's development.	—	3	—	—	—	—	—	3
4.3.4 Mobilisation of resources for projects as needed	—	—	1	—	—	—	—	1
4.3.5 Participation in programmes initiatives of the EU Research Framework Programme	—	—	—	—	1	—	—	1

4.3.6 Securing funding for management capacity	—	—	—	—	—	—	1	1
4.4. Strengthen collaboration with the University in the implementation and development of projects	—	—	1	—	5	—	—	6
4.4.1 Derive teaching content from RDI projects' results.	—	—	—	—	1	—	—	1
4.4.2 Encourage the participation of students in the development of projects	—	—	—	—	1	—	—	1
4.4.3 Organize, coordinate and direct the activities in the Centre	—	—	1	—	—	—	—	1
4.4.4 Prepare students, company and university staff through specialized training	—	—	—	—	1	—	—	1
4.4.5 Strengthening research-based and practice-oriented teaching	—	—	—	—	2	—	—	2
Total general	**7**	**5**	**14**	**11**	**41**	**12**	**34**	**124**

Table 11.1: CFAA's KPIs

11.2 Proposed databases and classification scheme.

Database	Minimum information to be included	Notes
Critical Success Factors	Future potential	
	Partner satisfaction	
	Project goals and mission (knowledge generation)	
	Project management success factors	
KPIs	Historically used KPIs	
	KPIs per partner	
	KPIs per technology	
	KPIs per type of project	
Lessons Learned	Lessons learn report of the project	
	Lessons learned per partner	
	Lessons learned per technology	
	Lessons learned per type of project	
Partners' evaluation	Partners' evaluation of life cycle of the project	
	Partners' evaluation of the deliverable	
	Partners' evaluation per technology	
	Partners' evaluation per type of project	
	Partners' feedback about the future implementation of the project's deliverable.	
Project Evaluation	Milestones compliment	
	Project success evaluation	
	Qualitative evaluation	
	Quantitative evaluation	
Project Team Evaluation	Qualitative evaluation	
	Quantitative evaluation based on data accumulated throughout the project.	

Projects information	Activation date	
	Deliverable list	
	Due Date	
	Financing entity	
	Partners involved	
	Partners participation	
	Planned cost	
	Planned hours	
	Planned resources	
	Prioritization	
	Project' technology	
	Scope	
	Total cost	
	type of project	We proposed to classify the projects in the following categories: i) Creation or development of new product technology platform projects; ii) Innovation projects, iii) Product or technology enhancement projects, iv) Project oriented to new product or process.
Quality Evaluation	KPIs evaluation	
	Quality assessment of the tasks	We proposed to organise the information about the quality assessment on the following categories: i) Type of the project, ii) Classification of the Activity, iii) Used resources
	Quality Control Activities	
	Quality evaluation per partner	
	Quality evaluation per technology	
	Quality evaluation per type of project	
Risk Assessment	Ongoing project risks identification	
	Previously identified risks (evaluation in terms of probability and impact)	
	Risk mitigation activities	

Tasks	Classification of activity	We propose to classify the activities according to the following criteria: i) Tests preparation, ii) Related activities to the set up of the project, iii) Literature writing activities, iv) Maintenance activities, v) Visits attendance, vi) Courses attendances, vii) Data analysis, viii) Reports writing
	Description of activities	
	Lessons learned	
	Technical performance evaluation	
	Time planned	
	Time spent	
	Type of activity	We propose to organise the information about the type of activity according to the following criteria: i) Meeting, ii)Project Definition, iii) Research, iv) Design, v) Development, vi) Test, vii) Measurement, viii) Release
	type of used resources	
	Used resources	
Used Resources	Classification of activity	
	Person in charge of the machine	
	Time spent	
	Type of activity	
	Type of project	

Table 11.2: Proposed Databases and classification scheme

11.3 Critical Success Criteria as in Sastoque et al. [10]

ID	Category	Description
CSC - 1	CSC - Cost Management	Return on Investment of the project
CSC - 2	CSC - Knowledge Management	Knowledge generation regarding project activities (e.g., tools, techniques, approaches, processes)
CSC - 3	CSC - Quality Management	Customer satisfaction regarding the deliverable.
CSC - 4		Customer satisfaction regarding the quality of delivery activities of the specific project
CSC - 5		Degree to which the deliverable meets its intended purpose.
CSC - 6		The deliverable meet the defined quality criteria.
CSC - 7	CSC - Risk Management	Workplace Safety
CSC - 8	CSC - Scope Management	Project goal was achieved
CSC - 9	CSC - Stakeholder Management	Delivery activities have a good reputation
CSC - 10		Reputation of the organization has increased

Table 11.3: Critical Success Criteria as in Sastoque et al. [10]