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Front Pages

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The current issue is the first of the thirteenth volume of the *Athens Journal of Technology & Engineering (AJTE),* published by the Engineering & Architecture Division of Athens Institute.

Gregory T. Papanikos
President
Athens Institute

16th Annual International Conference on Civil Engineering
22-26 June 2026, Athens, Greece

The Civil Engineering Unit of ATINER is organizing its **16th Annual International Conference on Civil Engineering, 22-26 June 2026, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering. The aim of the conference is to bring together academics and researchers of all areas of Civil Engineering other related areas. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2026/FORM-CIV.doc).

Academic Members Responsible for the Conference

- **Dr. Dimitrios Goulias**, Head, Civil Engineering Unit, ATINER and Associate Professor & Director of Undergraduate Studies Civil & Environmental Engineering Department, University of Maryland, USA.

Important Dates

- Abstract Submission: **3 March 2026**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **25 May 2026**

Social and Educational Program

The Social Program Emphasizes the Educational Aspect of the Academic Meetings of Athens Institute.

- Greek Night Entertainment (This is the official dinner of the conference)
- Athens Sightseeing: Old and New-An Educational Urban Walk
- Social Dinner
- Mycenae Visit
- Exploration of the Aegean Islands
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The Industrial Engineering Unit of ATINER will hold its **14th Annual International Conference on Industrial, Systems and Design Engineering, 22-26 June 2026, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering.The aim of the conference is to bring together academics, researchers and professionals in areas of Industrial, Systems, Design Engineering and related subjects. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2026/FORM-IND.doc).

Important Dates

- Abstract Submission: **3 March 2026**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **25 May 2026**

Academic Member Responsible for the Conference

- **Dr. Theodore Trafalis**, Director, Engineering & Architecture Division, ATINER, Professor of Industrial & Systems Engineering and Director, Optimization & Intelligent Systems Laboratory, The University of Oklahoma, USA.

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- Ancient Corinth and Cape Sounion

More information can be found here: https://www.atiner.gr/social-program

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Exploring the Correlation between Project Management Skills and Entrepreneurial Skills in South African Civil Engineering

By Polycarpe Feussi, Charles Mbohwa± & Mnqobiwezizwe Dlamini°*

This study investigates the correlation between project management competencies and entrepreneurial skills by reviewing existing scholarly literature. The central objective is to analyse the extent to which project management competencies such as planning, coordination, and execution—enhance the success of entrepreneurial ventures. Furthermore, the research examines the role of entrepreneurial skills, including innovation, risk-taking, and opportunity recognition, in facilitating effective project management outcomes. By integrating contemporary research findings regarding these two skill sets, this study aspires to offer valuable insights into how individuals can effectively harness both project management and entrepreneurial competencies to achieve their goals within the contemporary and dynamic business landscape. The study reveals a notable association between entrepreneurial skills and project management capabilities within universities, particularly in technology, engineering, and environmental disciplines. The findings suggest that modern project managers should prioritise the development of their entrepreneurial skills in conjunction with their project management skills, treating their projects as if they are their enterprises. This research delivers significant insights for practitioners, educators, and policymakers, thereby contributing to the enhancement of a robust and entrepreneurial civil engineering sector in South Africa.

Keywords: *project management skills, entrepreneurial skills, entrepreneurial success, leadership skills, risk management*

Introduction

The South African Civil Engineering (ECSA) industry faces a decline in skilled professionals and new entrants, causing distress for firms. This decline is linked to fewer civil engineering graduates, slowed industry growth post-2010 FIFA World Cup projects, the 2014 public sector construction cartel scandal, low fees for emerging contractors, and an ageing workforce (Alabi & Fapohunda 2021). The ECSA is prioritizing new civil engineers' recruitment, leading to a skills shortage and challenges for firms. Recruiting entrepreneurial civil engineers is essential to tackle these issues. Entrepreneurial skills, gained through education and experience, are crucial for civil engineers entering entrepreneurship (Fitriani & Ajayi 2022). Since the Project Management Institute's 1969 inception, project management skills have gained

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importance. However, the relationship between entrepreneurial and project management skills remains unclear. This study investigates this relationship among trained civil engineers in South Africa, focusing on the importance and possession of both skill sets. The research includes a literature review and aims to assess the level of project management and entrepreneurial skills among civil engineering professionals in South Africa, explore their correlation, consider demographic factors, and offer recommendations based on findings (Van der Westhuizen 2017).

The future of civil engineering in South Africa depends on evolving practices into larger ventures or staying small. This research underlines the importance of project management and entrepreneurial skills for civil engineers' success. It examines civil engineering graduates' competencies in project management skills (PMS) and essential entrepreneurial skills for career growth (Ghorbani 2023a). Globalization, transformation, and technological progress have significantly changed the engineering field, leading to a skills shortage in South Africa. The South African Institute of Civil Engineers advocates developing core entrepreneurial competencies in education (Lamola et al. 2024). Entrepreneurship involves meeting client expectations innovatively for income generation (Åström, Reim & Parida, 2022). Project management also includes entrepreneurial roles, as practitioners ensure project work aligns with beneficiaries' needs and delivers stakeholder value (Åström et al. 2022).

The research objective explores the relationship between project management skills and entrepreneurial skills in South Africa's civil engineering projects. Adopting a positivist philosophy and quantitative methods, this study examines a specific sample. The research aims to create a model illustrating the integration of project management systems and entrepreneurial skills, providing principles and outcomes for newcomers in entrepreneurial project management.

Literature Review

Importance of Project Management Skills

Project management is essential in construction, where many projects exceed budgets and timelines. Despite recommendations from engineering societies, engineering programs do not prioritise project management. Construction educators should provide practical project management experience. Core skills include planning, managing, and controlling projects as outlined in the PMBOK® Guide. Effective project management is vital across industries, enabling streamlined processes, resource allocation, risk mitigation, and strategies to reduce project failure (Ghorbani 2023b). Competent project managers foster team collaboration and clarify roles. They manage the complexities of modern projects involving various stakeholders and constraints. Research indicates organizations with skilled project managers are more likely to complete projects on time and within budget (Parsamehr et al. 2023). Professional organizations like the Project Management Institute stress the value of certification and training (Amoah & Marimon 2021). While not all projects need advanced skills, most benefit from them, and in agile settings, having a project manager enhances alignment of objectives and increases the chance of success (Zadeh et al. 2024).

Importance of Entrepreneurial Skills

Entrepreneurship is crucial for economic development and prosperity in any nation (Antonovica et al. 2023). It involves more than just owning and managing a business. Entrepreneurship is about turning a good idea into a profitable company, and it often requires innovation, adaptability, and risk-taking. The journey to creating a truly successful company can be challenging and full of obstacles for entrepreneurs. Some entrepreneurs quickly find investors, clients, and a customer base, while others struggle, regardless of how brilliant their idea is, to gain traction in the competitive marketplace. This is mainly because successful entrepreneurs possess certain abilities that other entrepreneurs do not (Asaadi et al. 2023).

Entrepreneurial skills are the abilities that entrepreneurs bring to the market, enabling them to identify opportunities and seize them (Marinho et al. 2014). These skills help entrepreneurs pursue success and stability in a highly uncertain and volatile business environment. One characteristic of entrepreneurs is their possession of multiple entrepreneurial skills and their ability to learn and acquire new ones as their business progresses. Entrepreneurial skills are essential for entrepreneurial success and effectiveness. It is crucial to possess them in the right way. These skills have significant implications for promoting and enhancing competitiveness, as well as insulating an enterprise from the impact of external and internal factors. They also facilitate the important drive by most businesses to engage in activities that enhance their output. This aligns with Moradi et al. (2021) proposition that the development of entrepreneurial skills can contribute to positive progress for businesses, as they constantly engage in capacity building, such as training their workforce or adopting new technologies to improve overall output.

Common Traits between Project Managers and Entrepreneurs

Few researchers have discovered that the "start-up" stage in project management and the stage that the entrepreneurship phenomenon embraces are the same (Kuura & Lundin 2019). The practical requirements that many start-ups and entrepreneurial companies face are what are driving the fusion of project management and entrepreneurship themes. Young entrepreneurs typically need knowledge of various processes to minimize failures (Alici & Cengizoglu 2018). Additionally, contemporary entrepreneurial ventures are often carried out as projects or project series, so many authors argue that those involved in entrepreneurship should have a good understanding of project management. Schools, which play a role in shaping these entrepreneurs, are also responsible for providing them with project management skills (Kuura & Lundin 2019).

In addition to the overlap between the PMBOK approach and the stages of the entrepreneurial process, there has been investigation into the overlap between essential entrepreneurship competencies and those included in the PMBOK. It seems that the skills sought after in project management are also highly ranked among the characteristics of successful entrepreneurs (Alici & Cengizoglu 2018). Therefore, it has been concluded that many project managers today share similarities with successful entrepreneurs. The literature is rich in references that explore the significant similarities

and common traits between entrepreneurs and project managers (Nguyen-Duc et al. 2021). Several studies emphasize the fact that project management and entrepreneurship share common ground in aspects such as risk-taking, talent identification, team management, and project planning.

The Role of Project Management Skills in Entrepreneurship

The term "entrepreneurship" refers to the process of creating new businesses by identifying and exploiting business opportunities. This study examines the potential benefits of combining project management skills with entrepreneurial skills. Entrepreneurs can utilize project management skills when creating and developing a new business venture. Several authors, including Ward and Lee (2021) and Dacre et al. (2021), emphasize the importance of project management skills in increasing the chances of entrepreneurial success. Therefore, the main objective is to investigate whether project management skills are helpful in identifying and establishing a new business, and whether they can be considered entrepreneurial skills. Previous research has highlighted the significance of project management skills in entrepreneurship, as they greatly contribute to business success. Entrepreneurship is gaining recognition as a driving force for innovation, economic growth, and competitiveness. The complex social systems of entrepreneurial ecosystems, with their interconnected layers, require focused measures in different areas to foster successful entrepreneurial ventures. It has been suggested that entrepreneurs should develop specific skills, or at the very least, improve their existing skills, to minimize risks and increase the probability of success (Iqbal et al. 2022).

Relationship between Project Management Skills and Entrepreneurial Skills

Project management (PM) and project procurement have become essential strategies for organizations to survive (Nguyen-Duc et al. 2021). A civil engineer with an entrepreneurial mind-set must possess the ability to recognize opportunities that require project management, innovation, and strategic thinking in the execution of feasible projects. However, civil engineering, which focuses on design and construction, is different from the role of project managers who apply project management skills to add value to civil engineering projects. Dana et al. (2021) explore the concept of entrepreneurship as an inherent talent for sustainable development, economic growth, and poverty alleviation. They suggest that this ability can be nurtured through education, mentorship, and hands-on experience, aiming to empower aspiring entrepreneurs to harness their potential and drive positive change in society.

This dichotomy is discussed by Bunton et al. (2010), who view entrepreneurship as a major skill/activity that involves an individual's personal attitude or natural ability to initiate technology development for sustainable development, inclusive economic growth, and poverty eradication. This perspective is also shared by Bendle (2010) and Amit and Zott (2001) who define entrepreneurship as the ability to innovate and take risks.

To bring clarity and inform strategy, this study examines the relationship between project management skills (PMS) and entrepreneurial skills (ES) in civil engineering. This article presents empirical evidence on the relationship between project management skills and entrepreneurial skills in the South African civil engineering (CE) industry. The study was conducted using a cross-sectional design and employed an enumerator-administered quantitative survey method. Non-probability sampling methods, specifically convenience and snowball sampling, were utilized. A structured questionnaire was developed and pre-tested to ensure reliability. The survey underwent pilot testing, item purification, external measurement model validation, and checks for common method bias. Data was analysed using descriptive statistics in SPSS.

The Impact of Entrepreneurial Skills on Project Management

In the previous section, we focused on the importance of active engagement in business operations. Therefore, it may seem logical to combine the project with entrepreneurship, both theoretically and practically. Entrepreneurs have an instinct to innovate, driven by the need to make their business endeavours predictable and feasible, and to achieve their ultimate objective (Nguyen-Duc et al. 2021). This entrepreneurial instinct may have a strong impact on project managers (PMs) and project management professionals (PMPs) who perform their work simultaneously. Leon (2017) argues that the development of entrepreneurial skills would enhance the wisdom of business operations. It can motivate entrepreneurs to seek conventional training, formal education, and exposure to project management, ultimately helping them execute projects effectively.

Most projects are micro- and small-sized activities, and in these firms, the top management is usually responsible for managing or steering such projects. However, the Intuit Future of Small Business Report suggests that 83 percent of small and growing businesses are managed by individuals with critical project management skills. Similarly, the PMI reports that 88 percent of companies using high-performing project managers have enterprise-level corporate leadership to align project activities with organizational goals. Given the nature and position of top management in small firms, these important management responsibilities can be considered entrepreneurship. Based on this basic idea, it may be reasonable to believe that entrepreneurs are also recognized for the influence of their entrepreneurial skills on their project management-related activities, from a conventional perspective.

Entrepreneurial Skills in Civil Engineering

Construction stakeholders have made significant progress in improving traditional construction practices over the past five decades. They have achieved this by adopting principles from the process-driven and product-oriented construction industry. Exploring the relationship between project management knowledge and entrepreneurial abilities in the construction industry is crucial to addressing unknown aspects identified in the 2010 civil engineering requirements report.

The purpose of this study is twofold:

- To investigate the close connection, if any, between the level of project management abilities and entrepreneurial abilities among civil engineers working in the South African construction/civil engineering industry.
- To identify the entrepreneurial abilities that civil engineers should develop, considering their foundational project management knowledge.

Civil engineers possess a wide range of skills and competencies in initiating, planning, executing, controlling, utilizing, and completing projects. However, these skills vary among individuals. It is widely acknowledged that individuals can develop these skills into comprehensive and multifaceted project management abilities. In addition to these interdisciplinary abilities, civil engineers practicing in the highly competitive and dynamic global construction environment now need to demonstrate high-level entrepreneurial attributes that can enhance their business offerings. The purpose of this study is to determine whether experienced civil engineers perceive entrepreneurial and project management knowledge as distinct from each other.

Challenges in Developing Project Management and Entrepreneurial Skills

The development of project management and entrepreneurial skills is a multi-faceted process that presents several obstacles. These obstacles include the intricate nature of skills, limited resources, the ever-changing business environment, and mental barriers (Awan & Sroufe 2022). The complexity of these skills can be overwhelming for individuals and organizations, while constraints in resources can hinder their effective development. The rapidly evolving business environment also poses a challenge in keeping up with the necessary skills. Research in the field of education emphasizes the importance of training programs that encompass not only technical knowledge but also soft skills and adaptability (Caeiro-Rodríguez et al. 2021).

Business literature points out that many entrepreneurs struggle due to inadequate project management skills, leading to poor execution and resource management (Ismail Albalushi & Naqshbandi 2022). Case studies demonstrate that organizations that invest in comprehensive skill development tend to achieve better project outcomes and business viability (Zhang & Berhe 2022, Lamarre et al. 2023). The impact of these challenges may vary depending on an individual's background, prior experience, and specific organizational context. While online learning platforms have enhanced access to resources and training, their effectiveness can be inconsistent and may not cater to the specific needs of all learners. In conclusion, the development of project management and entrepreneurial skills presents a multitude of challenges, including skill complexity, resource limitations, environmental dynamics, and mindset barriers.

However, in current education, project planning is primarily associated with project management. In both project management and entrepreneurship, students need to develop skills that are beneficial for their professional development. The

main objective of project management is to ensure that projects are completed within the allotted time and budget, while meeting performance and functionality goals. Similarly, in entrepreneurship, students need to evaluate new ideas and develop a business model, including its value proposition. They also need to define the scope of work and set milestones, as well as negotiate with various stakeholders to find win-win solutions. Until now, project management and entrepreneurship have been taught separately (Hamzah & Othman 2023).

Developing entrepreneurship skills is not a straightforward process, but one strategy could be to provide students with opportunities for project-based and scenario-based learning (Boskovic et al. 2020). Similarly, project-based approaches are helpful in developing project management skills. Leung (2021) argued that, generally, students prefer technology-oriented methods and find theoretical topics less attractive. Perifanis and Kitsios (2023) recommended project-based learning with hands-on and student-centered activities to foster greater self-direction and interest in entrepreneurial studies, as they found it necessary for developing entrepreneurial skills. Another pedagogical approach is problem-based learning, which has been reported to stimulate learning motivation, responsibility, creativity, enthusiasm, and teamwork (Memon et al. 2018).

Examining the Introduction of Project Management in Entrepreneurship

A project manager or entrepreneur must possess a variety of skills to be successful, according to Morgan (2018). However, many individuals lack proficiency in these skills and only reach a minimal level of competence. Additionally, professionals may mistakenly assume that students possess sufficient problem-solving and critical thinking abilities. It is important to recognize that thinking influences attitudes and behaviours and understanding the factors that shape an individual's thinking process is crucial. It is also necessary to consider different perspectives on various issues. However, it is worth noting that an individual's confidence in their lack of bias can lead to bias.

Research Methodology and Method

This section discusses the design, sample criteria, and data collection methods used in a study. The research used a quantitative, cross-sectional survey design, which allows for data collection across large proportions of the population. Exploratory research commonly uses this method to establish baseline numbers, provide a snapshot of the current situation, and conduct simple research. The sample population was chosen from the probability random sample of the South African Institution of Civil Engineering (SAICE) of over ten thousand registered members. The study emphasizes the importance of appropriate data collection and sampling techniques.

The survey was utilised to collect a substantial amount of quantitative data, encompassing various measures and variables. The inferential and differential statistics, known for their effectiveness in analysing and interpreting complex data, were diligently employed for a thorough analysis (Kumar et al. 2023). To ensure

representative results, a meticulous and systematic probability random sampling technique was implemented, ensuring a fair distribution of respondents (Pawar et al. 2023).

The aim of this research was to examine the relationship between project management skills and entrepreneurial skills in the field of civil engineering. The researchers adopted a quantitative approach and randomly selected 340 engineers from a pool of over 10,000 registered engineers in the country. They conducted surveys to gather data on entrepreneurial and leadership abilities, which were subsequently analysed using statistical methods.

Results Presentation and Interpretations

To examine the connection between project management skills and entrepreneurial skills in the civil engineering field in South Africa, the influence of project management skills on the development of entrepreneurial skills in the construction industry of South Africa was assessed on a Likert scale ranging from slightly important to extremely important. This scale was used to measure the perception of the participants. The first results were presented in Table 1.

Table 1. *Simple Frequency Table*

PRENO1					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Slightly important skill	44	11.8	11.8	11.8
	Moderately important skill	2	.5	.5	12.3
	Very important skill	142	38.0	38.0	50.3
	Extremely important skill	186	49.7	49.7	100.0
	Total	374	100.0	100.0	

Source: Researchers own compilation (2023).

The frequency table displays data on the perceived significance of a skill, divided into four categories: "slightly important," "moderately important," "very important," and "extremely important." The table depicts the number of respondents who chose each category, with a total of 374 respondents. The percentages for each category are 11.8%, 0.5%, 38.0%, 49.7%, and 100%. The valid percentages eliminate any missing data and are identical to the percent column. The cumulative percentage indicates the cumulative distribution of the responses. More than 88.7% of the respondents rated the skill as "very important" or "extremely important," whereas only a small proportion rated it as "slightly important" (11.8%) or "moderately important" (0.5%). This suggests that the skill is generally considered important or very important by a substantial majority of respondents. The table offers a comprehensive insight into the perceived importance of a skill. That implies that indeed the project management skill and entrepreneurial skills and positively correlated although the causal relationship has not been established. It is thus expected from the project manager to have more entrepreneurial skill, which entails risk taking, good communications and good leadership. Now that the positive correlation is established, it is important to establish the strength of the correlation as presented in Table 2.

Table 2. *Correlation Analysis*

Symmetric Measures					
		Value	Asymptotic Standardized Error	Approximate T[b]	Approximate Significance
Interval by Interval	Pearson's R	.004	.054	.076	.939[c]
N of Valid Cases		374			

Source: Researchers own compilation (2023).

Correlation Analysis

The correlation coefficient quantifies the strength and direction of a linear association between two continuous variables. It is important to note that correlation does not imply causation. It is also worth mentioning that a low correlation coefficient does not necessarily imply independence between the variables, as there might still exist a non-linear relationship. In such cases, polynomial regression analysis can be employed to identify non-linear associations (Güzel et al. 2022).

Correlation analysis is a method used to determine the level of relationship between two variables. It is measured on a scale from -1 to 1 ($-1 \leq r \leq 1$). The Pearson correlation coefficient R is specifically used to evaluate the strength of association between two continuous variables (Chen et al. 2009). The coefficient ranges from -1 to +1, with values closer to -1 or +1 indicating a stronger association. To assess the linearity of the relationship graphically, a scatter plot can be employed. If the data points align in a straight line, correlation analysis can be applied (Shin et al. 2023). Thus, a value of 0.004 suggests a very weak linear relationship between variables. The positive sign indicates that higher values of one variable are associated with higher values of the second variable, and vice versa (Taylor 2020). In the case of weak correlations, the inferential models used do not have enough power to fully explore the relationships between variables. The value of 0,004 shows that there indeed a very low correlation hence less than 0.2.

Table 3. *Engineering Field * PRENO1*

Crosstab						
		PRENO1				Total
		Slightly important skill	Moderately important skill	Very important skill	Extremely important skill	
Engineering field	Construction	28	2	106	124	260
	Geotechnical	0	0	2	2	4
	Water resources	9	0	16	31	56
	Structural	7	0	18	29	54
Total		44	2	142	186	374

Source: Researchers own compilation (2023).

Table 3 reveals important insights into the link between engineering expertise and entrepreneurial skills, illustrating their interdependence within the industry. A frequency table is a useful tool for organizing and presenting data. It counts how often each value appears in a dataset. The table usually has two columns: one for the values or categories being counted, and another for the frequency or count of each value. This table summarizes and analyses categorical data. The civil engineers were categorized into construction, geotechnical, water resources, and structure.

Construction is the area with the most responses, particularly in the "very important" (106) and "extremely important" (124) categories, which indicates a strong acknowledgement of the significance of skills in this field. In contrast, the geotechnical field receives the fewest total responses (4) and does not feature in the slightly and moderately important categories, indicating a potential lack of widespread perception of the value of skills in this field or a lack of feedback in this domain. Water resources and structural fields also have noteworthy response numbers, although they are much lower than construction, and there is an emphasis on skills being "extremely important." All categories consistently perceive skills as "very important" or "extremely important," signifying a widespread agreement on the crucial role these skills play in engineering disciplines.

Results & Discussion

Competence in project management and entrepreneurship is vital for effectively carrying out civil engineering projects in South Africa. The intricate nature of these projects, along with economic conditions, sustainability, and innovation, makes both sets of skills necessary. South Africa's complex projects, involving multiple stakeholders, tight deadlines, and regulatory compliance, require integrated project delivery methods. Successful public-private partnerships in infrastructure development serve as examples of how entrepreneurial skills enable project managers to identify innovative funding solutions and partnerships.

Given South Africa's unique socio-economic landscape, combining these skill sets is crucial for delivering projects that address community needs and comply with regulations. Professional associations such as SAICE advocate for the integration of project management and entrepreneurial skills through professional development programs and certifications. Case studies demonstrate that teams with strong entrepreneurial and project management skills achieved better outcomes by leveraging innovative solutions and techniques. Research findings show that entrepreneurial thinking often leads to better resource allocation, more effective risk management, and ultimately, project success in emerging markets.

While the correlation between project management and entrepreneurial skills is strong, their presence may not guarantee success due to factors such as market conditions, team dynamics, and external economic factors. Nevertheless, possessing both sets of skills significantly enhances the potential for successful and sustainable civil engineering projects. In highly regulated environments, market demands, and stakeholder expectations are evolving, requiring project managers to adopt entrepreneurial approaches to remain competitive and efficient.

In conclusion, project management and entrepreneurial skills complement each other in South Africa's civil engineering landscape, allowing project managers to navigate complexities more effectively, leading to successful project delivery and innovation in practice.

Civil engineering projects in South Africa can be quite challenging due to a variety of factors, including socio-economic issues, regulations, and the need for innovation. Effective project management is essential for successfully navigating these complexities. Resource management, which involves strategic allocation of time, budget, and human capital, is another vital aspect of civil engineering projects (Jain & Singh 2023). To thrive in changing market conditions, entrepreneurs must embrace adaptability and innovation (Coghlan et al. 2020). Project managers also need to be ready to confront unforeseen challenges and implement innovative solutions to achieve project objectives. Engaging effectively with stakeholders is crucial for project managers, while entrepreneurs should focus on building and maintaining relationships to take advantage of opportunities (Bahadorestani et al. 2020).

Civil engineers, particularly in South Africa where infrastructure development is crucial for economic growth, emphasise the importance of both successful project completion and entrepreneurial efforts. Integrating these skill sets can enhance project efficiency, but the degree of their connection may vary based on project size, scope, and circumstances. Smaller projects may rely more on entrepreneurial abilities, while larger ones may prioritize project management expertise. Emphasizing project management in civil engineering is crucial due to its organized characteristics, yet it's also essential to recognize the evolving nature of the field (Bentalha & Alla 2024). Creative problem solving and flexibility are necessary for addressing new challenges and seizing emerging opportunities. Without an entrepreneurial mindset, projects can stagnate and struggle to adapt. In summary, the combination of project management and entrepreneurial skills is essential for the success and long-term viability of civil engineering projects in South Africa. Integrating these two skills is crucial to propel the future advancement of the civil engineering sector in South Africa.

Recommendations

In South Africa, higher education institutions should prioritise the development of project management skills among students, especially those studying engineering. One effective way to achieve this is through close collaboration with industry. Encouraging students to take on practical projects is highly beneficial as it allows them to apply their classroom knowledge and bridge the gap between theory and practice. For engineering students to truly grasp the practical value of their knowledge, it is crucial for them to have hands-on experience. This exposure to real-world working environments will also help them transition smoothly into the workforce after graduation, benefiting both the students and potential employers. In conclusion, this study emphasizes the importance of six project management skills - communication, problem-solving, resource management, leadership, decision-making, and flexibility - for the entrepreneurial skills of civil engineering project managers in South Africa.

Therefore, we propose the following recommendations to enhance the development of entrepreneurship skills among civil engineering project managers in South Africa.

Conclusion

The research demonstrates a significant link between entrepreneurial skills and project management skills in universities, specifically in technology, engineering, and environmental departments. The findings indicate that today's project managers should focus on developing their entrepreneurial skills alongside their project management skills, treating projects as their own businesses. Project teams should support project managers in utilizing their underlying entrepreneurial skills in project management. Modern project management training and programs should incorporate entrepreneurial skills, in addition to hard and soft skills, to better equip future project managers. However, the research faces challenges such as the accuracy of data due to self-administered questionnaires and the generalizability of the population. Future research should explore project management skills and entrepreneurial skills in other fields or levels of entrepreneurship, such as civil engineering in South Africa. The findings suggest that project management skills, including leadership, communication, problem-solving, and teamwork, are applicable in any entrepreneurial field. This applicability is evident in the South African civil engineering industry, where many professionals utilize project management skills to run their firms as entrepreneurial ventures. However, it is necessary to establish a potential relationship between the utilization of project management skills and the ability to transform a civil engineering practice into a more entrepreneurial venture.

References

Alabi B, Fapohunda J (2021) Effects of increase in the cost of building materials on the delivery of affordable housing in South Africa. *Sustainability* 13(4): 1772.

Alici EN, Cengizoglu E (2018) *The Effect of Knowledge Management in Start-ups: Exploring the Transition Process of a Start-up from Temporary to a Permanent Organization*. Available at: https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1182103&dswid=3824.

Amit R, Zott C (2001) Value creation in e-business. *Strategic Management Journal* 22(6–7): 493–520.

Amoah A, Marimon F (2021) Project managers as knowledge workers: competencies for effective project management in developing countries. *Administrative Sciences* 11(4): 131.

Antonovica A, de Esteban Curiel J, Herráez BR (2023) Factors that determine the degree of fulfilment of expectations for entrepreneurs from the business incubator programmes. *International Entrepreneurship and Management Journal* 19(1): 261–291.

Asaadi A, Atrian A, Hoseini HN, Movahedi MM (2023) *Risk Analysis in the Selection of Project Managers Based on ANP and FMEA*. arXiv preprint arXiv:2311.03224.

Åström J, Reim W, Parida V (2022) Value creation and value capture for AI business model innovation: a three-phase process framework. *Review of Managerial Science* 16(7): 2111–2133.

Awan U, Sroufe R (2022) Sustainability in the circular economy: insights and dynamics of designing circular business models. *Applied Sciences* 12(3): 1521.

Bahadorestani A, Naderpajouh N, Sadiq R (2020) Planning for sustainable stakeholder engagement based on the assessment of conflicting interests in projects. *Journal of Cleaner Production* 242(Jan): 118402.

Bendle NT (2010) *Out-group homogeneity bias and strategic market entry*. University of Minnesota.

Bentalha B, Alla L (2024) Revealing the subtleties: The art of qualitative studies in science and management. In *Applying qualitative research methods to management scienc*e, 1–21. IGI Global.

Boskovic D, Borovina N, Zukic M (2020) *Stimulating Entrepreneurship in Teaching Human Computer Interaction.* arXiv preprint arXiv:2011.09001.

Bunton M, Levey Z, Podeh E (Eds.) (2010) *Britain and the Middle East: From Imperial Power to Junior Partner.* Brighton: Sussex Academic Press.

Caeiro-Rodríguez M, Manso-Vázquez M, Mikic-Fonte FA, Llamas-Nistal M, Fernández-Iglesias MJ, Tsalapatas H, et al. (2021) Teaching soft skills in engineering education: An European perspective. *IEEE Access* 9(Feb): 29222–29242.

Chen X, Li Q, Wang J, Guo X, Jiang X, Ren Z, Weng C, et al. (2009). Identification and characterization of novel amphioxus microRNAs by Solexa sequencing. *Genome Biology* 10(7): R78.

Coghlan C, Labrecque J, Ma Y, Dube L (2020) A biological adaptability approach to innovation for small and medium enterprises (SMEs): Strategic insights from and for health-promoting agri-food innovation. *Sustainability* 12(10): 4227.

Dacre N, Senyo PK, Reynolds D (2019) Is an engineering project management degree worth it? Developing agile digital skills for future practice. *Engineering Education Research Network*. SSRN.

Dana LP, Tajpour M, Salamzadeh A, Hosseini E, Zolfaghari M (2021) The impact of entrepreneurial education on technology-based enterprises development: The mediating role of motivation. *Administrative Sciences* 11(4): 105.

Fitriani H, Ajayi S (2022) Preparing Indonesian civil engineering graduates for the world of work. *Industry and Higher Education* 36(4): 471–487.

Ghorbani A (2023a) A review of successful construction project managers' competencies and leadership profile. *Journal of Rehabilitation in Civil Engineering* 11(1): 76–95.

Ghorbani M (2023b) Green Knowledge Management and Innovation for Sustainable Development: A Comprehensive Framework. In *ECKM 2023 24th European Conference on Knowledge Management Vol 1*. Academic Conferences and publishing limited.

Güzel İ, Munch E, Khasawneh FA (2022) Detecting bifurcations in dynamical systems with CROCKER plots. *Chaos: An Interdisciplinary Journal of Nonlinear Science* 32(9).

Hamzah MI, Othman AK (2023) How do locus of control influence business and personal success? The mediating effects of entrepreneurial competency. *Frontiers in Psychology* 13: 958911.

Iqbal J, Asghar MZ, Asghar A, Waqar Y (2022) Impact of entrepreneurial curriculum on entrepreneurial competencies among students: The mediating role of the campus learning environment in higher education. *Frontiers in Psychology* 13: 950440.

Ismail Albalushi K, Naqshbandi MM (2022) *Factors affecting success and survival of small and medium enterprises in the Middle East*. Knowledge. mdpi.com.

Jain A, Singla A (2023) Examining the link between entrepreneurialism and employability: A literature review. *Asia-Pacific Journal of Management Research and Innovation* 19(4): 219–230.

Kumar A, Kapil A, Ahlawat D (2023) Exploring The Data Science. In *2023 7th International Conference On Computing, Communication, Control And Automation (ICCUBEA)*, 1–7. IEEE.

Kuura A, Lundin RA (2019) Process perspectives on entrepreneurship and projects. *International Journal of Managing Projects in Business* 12(1): 25–47.

Lamarre E, Smaje K, Zemmel R (2023) *Rewired: the McKinsey Guide to Outcompeting in the Age of Digital and AI*. John Wiley & Sons.

Lamola M, Pooe D, Munongo S (2024) Organisational innovation and gender diversity: Insights from the civil engineering industry. *Acta Commercii* 24(1): 1–12.

Leon RD (2017) Developing entrepreneurial skills. An educational and intercultural perspective. *Journal of Entrepreneurship, Management and Innovation* 13(4): 97–121.

Leung NH (2021) Transmissibility and transmission of respiratory viruses. *Nature Reviews Microbiology* 19(8): 528–545.

Marinho ML, Sampaio SCB, Lima TLA, Moura HP (2014) *A guide to deal with uncertainties in software project management.* arXiv preprint arXiv:1411.1920.

Memon J, Rozan MZA, Ismail K, Jahanzeb A (2018) *Mentor Protege Matchmaking Framework for IT Entrepreneurs: A Qualitative Study*. arXiv preprint arXiv:1808. 04724.

Moradi E, Jafari SM, Doorbash ZM, Mirzaei A (2021) Impact of organizational inertia on business model innovation, open innovation and corporate performance. *Asia Pacific Management Review* 26(4): 171–179.

Morgan BJ (2018) *Analysis of quantal response data*. Chapman and Hall/CRC.

Nguyen-Duc A, Kemell KK, Abrahamsson P (2021) The entrepreneurial logic of startup software development: A study of 40 software startups. *Empirical Software Engineering* 26: 1–55.

Parsamehr M, Perera US, Dodanwala TC, Perera P, Ruparathna R (2023) A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management. *Asian Journal of Civil Engineering* 24(1): 353–389.

Pawar PB, Verma R, Daniel CO, Sayyad L (2023) *Foundation of Research Methodology: A Comprehensive Guide*. Red Unicorn Publication.

Perifanis NA, Kitsios F (2023) Investigating the influence of artificial intelligence on business value in the digital era of strategy: A literature review. *Information* 14(2): 85.

Shin S, Yu Y, Lee K (2023) *Enhancing low-resolution face recognition with feature similarity knowledge distillation*. arXiv preprint arXiv:2303.04681.

Taylor BM (2020) *A multi-way correlation coefficient*. arXiv preprint arXiv:2003.02561.

Van der Westhuizen T (2017) Theory U and individual entrepreneurial orientation in developing youth entrepreneurship in South Africa. *Journal of Contemporary Management* 14(1): 531–553.

Zadeh EK, Khoulenjani AB, Safaei M (2024) Integrating AI for agile Project Management: Innovations, challenges, and benefits. *International Journal of Industrial Engineering and Construction Management* 1(1): 1–10.

Zhang Y, Berhe HM (2022) The impact of green investment and green marketing on business performance: The mediation role of corporate social responsibility in Ethiopia's Chinese textile companies. *Sustainability* 14(7): 3883.

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Design of Rolling Bearings for their use in Potentially Explosive Atmospheres – A Systematic Review

By Leo Siegle, Sabrina Herbst± & Frank Engelmann°*

There is currently no single guideline for the design of rolling bearings for use in potentially explosive atmospheres. Although one section of the ISO 80079-37 standard refers specifically to rolling bearings in the context of design in accordance with the principle of design safety, this section mainly refers to other standards and manufacturers' specifications. This work is intended to identify and summarize current standards, guidelines, technical rules and other research results on the subject of the design of rolling bearings within the framework of a systematic review and thereby create a basis for a guideline for the design of rolling bearings. In addition, further research approaches are to be derived from the current state of the art.

Keywords: *roller bearing, non-electrical explosion protection, explosive atmospheres, ATEX*

Introduction

In all industrial and private applications requiring work with flammable gases or dusts, an explosion must be expected in the worst case. This danger can be countered with suitable actions from the field of explosion protection. The primary aim of explosion protection measures is to prevent the creation or ignition of an explosive atmosphere. Here, applications from electrical or non-electrical explosion protection are used accordingly. If this is not possible, the propagation of the explosion should be kept to a minimum.

The handling of explosion protection is regulated by law in most industrialized countries. In Europe, these regulations are set out in EU Directive 2014/34/EU. At the German level, the EU directive is implemented by corresponding standards.

For development reasons, non-electrical explosion protection is comparatively little represented in standardization. Explosion protection originated underground, where attempts were made then, as now, to prevent the occurrence of electrical ignition sources by means of suitable protective measures. The development began in 1909 with the first flame-proof pit lamp for the mining industry (Eaton's Crouse-Hinds Business 2013). Electrical ignition sources have long been the focus of explosion protection. Only over time have non-electrical ignition sources been considered in more detail as part of the standardization process. However, this is how non-electrical explosion protection plays a major role in reality. According to Bartknecht, non-

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electrical ignition sources cause about 30% of industrial deflagrations and explosions (Bartknecht & Zwahlen 2013). A common ignition source is the hot surface of a machine element. This ignition source is often caused by the friction of parts in relative motion.

This phenomenon can also be observed in rolling bearings. The heating that occurs here is not critical in normal operation if the bearings are designed correctly, maintained appropriately and mounted correctly. It is always necessary to take a close look at the prevailing operating conditions, record any temperature limit values and include them in the bearing design. If the assumed parameters deviate from their nominal values due to incorrect design, mounting or maintenance, a rolling bearing can quickly become a source of ignition.

The aim of this work is to summarize the design of rolling bearings with regard to their use in potentially explosive atmospheres in accordance with current standardization and to supplement this with a systematic review of current research findings.

Basic Explosion Protection

The prevention of explosion hazards is regulated by law in most industrialized countries. In the European Union, explosion protection is regulated in the so-called ATEX Directive 2014/34/EU standardized. This includes the harmonization of the country-specific laws of the member states for equipment, protective systems and components for the intended use in potentially explosive atmospheres. The ATEX directive defines basic safety requirements and leaves the technical specification to the European standards. The IEC 60079 ff series of standards deals with electrical explosion protection, while ISO 80079 ff describes the measures for non-electrical explosion protection.

The technical concretization and specific implementation recommendations of the individual standards can be found in national technical regulations and recommendations. In Germany, these can be found in the corresponding VDI guidelines and in various technical rules for operational safety or for hazardous substances, TRBS or TRGS for short.

In addition, the ATEX Directive regulates the conformity assessment and marking of products in potentially explosive atmospheres. As a fully harmonized directive, the ATEX Directive 2014/34/EU replaces all existing divergent national and European legislation on the same subjects.

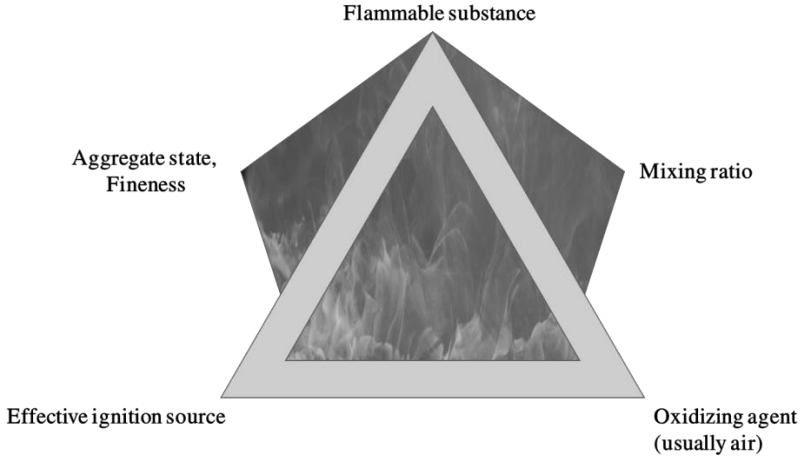
Basically, the EN 1127-1 regulates Procedures for recognizing and evaluating hazardous situations in which ignition of an explosive atmosphere can potentially occur. The standard provides guidance for risk assessment and describes suitable planning and manufacturing measures to reduce these risks and increase safety.

Furthermore, the standard deals with various parameters that must be in a defined mixing ratio spatially and temporally to each other in order to justify an explosion. These are influenced by:

- the presence of a flammable/combustible substance;
- the degree of dispersion of the flammable/combustible substance (e.g. gases, vapors, mists, dusts);
- the concentration of the flammable/combustible substance in the air within the explosion range (mixing ratio);
- the amount of explosive atmosphere sufficient to cause injury or damage in the event of ignition.

If the mixture described above now meets an ignition source in a suitable explosive ratio, an explosion will consequently occur (see Figure 1). This must be prevented by suitable explosion protection measures.

Figure 1. *Explosion Pentagon*



All assumptions made in the context of explosion protection must be considered in the light of the atmospheric conditions specified in EU Directive 2014/34/EU. These are generally understood to be ambient temperatures of -20 °C to +60 °C, a pressure range of 0.8 bar to 1.1 bar, and an oxygen content in the air of 21%. (Europäische Union 2014).

The standards IEC 60079-10-1 and IEC 60079-10-2 describe the essential principles for the classification of potentially explosive atmospheres according to the probability of the presence of an explosive atmosphere. Within the standards, a distinction is made between the zones described in Table 1 depending on the occurrence of the potentially explosive atmosphere.

Table 1. *Classification of Zones*

Medium	Zone	Definition
Gas	2	Area in which an explosive gas atmosphere is not expected to occur during normal operation ; if it does occur, it will only be of short duration.
	1	Area in which an explosive gas atmosphere is likely to occur periodically or occasionally during normal operation.
	0	Area in which an explosive gas atmosphere is present continuously, for a long period of time or frequently.
Dust	22	Area in which an explosive dust atmosphere in the form of a cloud of combustible dust in air is not likely to occur during normal operation; if it does occur, however, it will only be for a short period of time
	21	Place where a potentially explosive dust atmosphere in the form of a cloud of dust in air occurs occasionally during normal operation
	20	Place where an explosive dust atmosphere in the form of a cloud of dust in air is present continuously or for a long period of time or frequently

Source: Europäische Union 2014.

In order to specify the use of the corresponding devices with regard to the permissible operating temperatures, the maximum permissible surface temperatures are divided into temperature classes from T1 to T6. The subdivision can be found in Table 2 and is based on IEC 60079-0.

Table 2. *Maximum Permissible Surface Temperatures*

Temperature classes	Ignition temperature range of the mixtures	Permissible surface temperature of the devices	Example substances
T1	> 450 °C	450 °C	Hydrogen
T2	> 300 °C ... < 450 °C	300 °C	Ethylene
T3	> 200 °C ... < 300 °C	200 °C	Gasoline
T4	> 135 °C ... < 200 °C	135 °C	Ethyl ether
T5	> 100 °C ... < 135 °C	100 °C	
T6	> 85 °C ... < 100 °C	85 °C	Carbon disulfide

Source: Europäische Union 2014.

The ISO 80079-36 also defines the requirements for equipment to be used in explosion-proof areas and classifies them according to an EPL (Equipment Protection Level) standard. The subdivision is compared with the zone classification from standards IEC 60079-10-1/2 in Table 3.

Table 3. *Comparison of Zoning and EPL Level*

ATEX 2014/34/EU			IEC 60079-10-1 IEC 60079-10-2	ISO 80079-36/37			
Device category	Level of security	Zones	Group	Protection level EPL	Safe for		
					Normal operation	Expected disturbance	Rare disorder
1G	very high	0, 1, 2	II (gas)	Ga	x	x	x
2G	high	1, 2		Gb	x	x	
3G	normal	2		Gc	x		
1D	very high	20, 21, 22	III (dust)	Da	x	x	x
2D	high	21 ,22		Db	x	x	
3G	normal	22		Dc	x		

Source: IEC, IEC 60079-10-1.; IEC, IEC 60079-10-2.

Research Needs and Methodology

Although, as mentioned at the beginning, non-electrical ignition sources cause around 30% of industrial deflagrations and explosions, non-electrical ignition sources are currently given little consideration in standardization. In particular, machine elements which can themselves become a source of ignition, such as belt drives, springs or rolling bearings, are not fully dealt with in standardization. For this reason, the present paper is intended to take a closer look at the current state of the art with regard to the procedure for designing rolling bearings for use in potentially explosive atmospheres. Current standards, technical rules, guidelines and other publications in the field of rolling bearing application in potentially explosive atmospheres are to form the basis of the elaboration.

The current state of the art will be based on a systematic literature review following Prielipp et al. (2022) to be elaborated. The research and analysis of standards will follow Mangelsdorf's (2019) study.

The specific research question is: "How should rolling bearings be designed according to the current state of the art for their use in potentially explosive atmospheres?". The aim is to comprehensively present the current state of the art according to standardization, taking into account current research results, including all references, and thus to create the basis for a guide to the design of rolling bearings for use in potentially explosive atmospheres.

For a clear definition and delimitation, this elaboration relies on a categorization of the established taxonomy for literature reviews according to Cooper (1988). The chosen categories of the taxonomy can be seen in Table 4.

Table 4. *Taxonomy of Literature Review*

Characteristic	Categories			
Focus	Research Outcomes	Research Methods	Theories	Applications
Goal	Synthesis	Critical view	Identification of central question	
Perspective	Neutral reproduction		Critical position	
Coverage	Exhaustive	Exhaustive and Selective	Representative	Selective
Organization	Historic	Conceptual	Methodological	
Audience	Specialized Scholars	General Scholars	Practitioners/ Politicians	General Public

The focus of the elaboration is on previous research results and the concrete application recommendations and methods of the standards, technical rules and guidelines. The aim of the work is to synthesize by combining different sources and to identify central issues. The review is intended to reflect the current state of the art as completely and neutrally as possible. The organization of the literature in the review is conceptually methodical. The paper is primarily aimed at subject matter experts and practitioners.

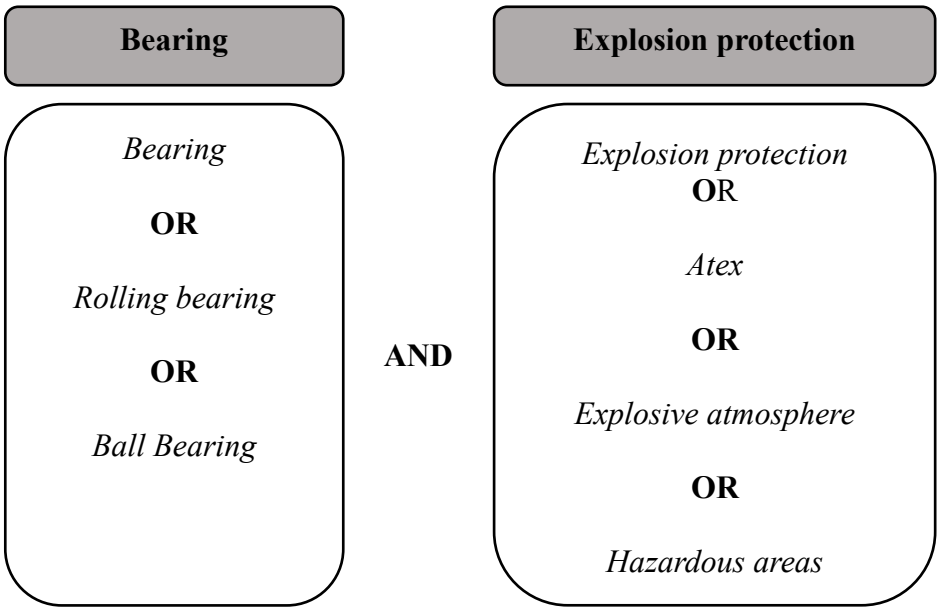
Standards, technical rules, guidelines and other publications in this field are taken into account. The standards analyzed must be ISO, EN or DIN standards. Technical rules or guidelines included must be recognized for their consideration in Germany.

Regarding scientific publications, due to the poor data situation, publication of the last 20 years (from 2003-2023) are considered after the search for publications in the last 10 years (from 2013-2023) provides insufficient results. For obtaining a scientific grade, only peer-reviewed publications are considered.
The keywords used based on the research question:

- Bearing (machine element)
- Explosion protection

The search terms derived from this are shown in Table 5.

Table 5. *Search Terms*

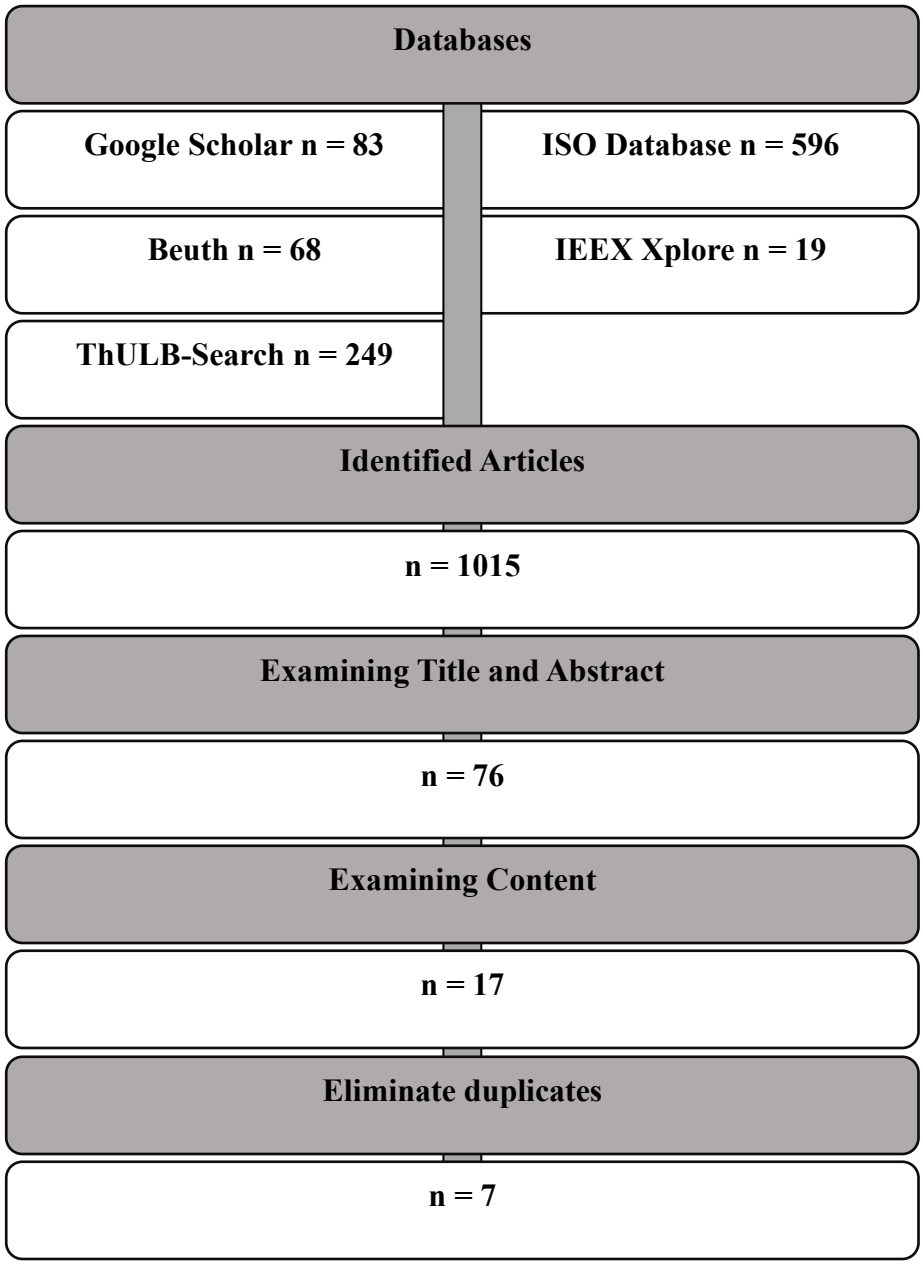


Literature searches are conducted in various databases as well as in topic-specific journals. The databases searched are:

- Google Scholar (https://scholar.google.de/)
- ISO database (www.iso.org)
- Beuth (www.beuth.de)
- IEEE Xplore (https://ieeexplore.ieee.org/)
- ThULB search (https://www.thulb.uni-jena.de/home) incl:
    - JSTOR
    - Web of Science
    - Scopus
    - DOAJ: Directory of Open Access Journals
    - OAPEN: Online library and publication platform

The search based on the search terms resulted in 1015 hits. Taking into account the search result requirements, the removal of duplicates, and after evaluating the title, abstract, and content, the number of relevant search results is reduced from 1015 to 7 publications and articles (Table 6).

Table 6. *Databases*



The articles and publications relevant for the review are then evaluated with regard to their relevance using a point scale of 0-3 (0 = not relevant, 3 very relevant). Papers with a relevance of 0 are not considered further. Papers with no reference to the research question will be awarded 0 points. If a paper provides concrete recommendations for action or interpretation, it is given a relevance score of 3.

Table 7 shows the relevant (scale > 1) articles and publications considered in this review.

Table 7. *Sources*

Standard/Author	Relevance
DIN CEN/TR 16829	3
DIN EN 14986	2
DIN EN ISO 80079-36:2016-12	2
DIN EN ISO 80079-37:2016-12	3
VDI 2263:2018-07	1
Pieters and Perbal (2011)	2
Rumbak et al. (2010)	3

Results

In the following, the contents of the identified literature will be summarized. In order to obtain a holistic overview of the design of rolling bearings for use in potentially explosive atmospheres, any references (such as in ISO 80079-37 reference to manufacturer's specifications) are included in the results.

Classification of Rolling Bearings for use in Potentially Explosive Atmospheres According to ISO 80079-36 and -37

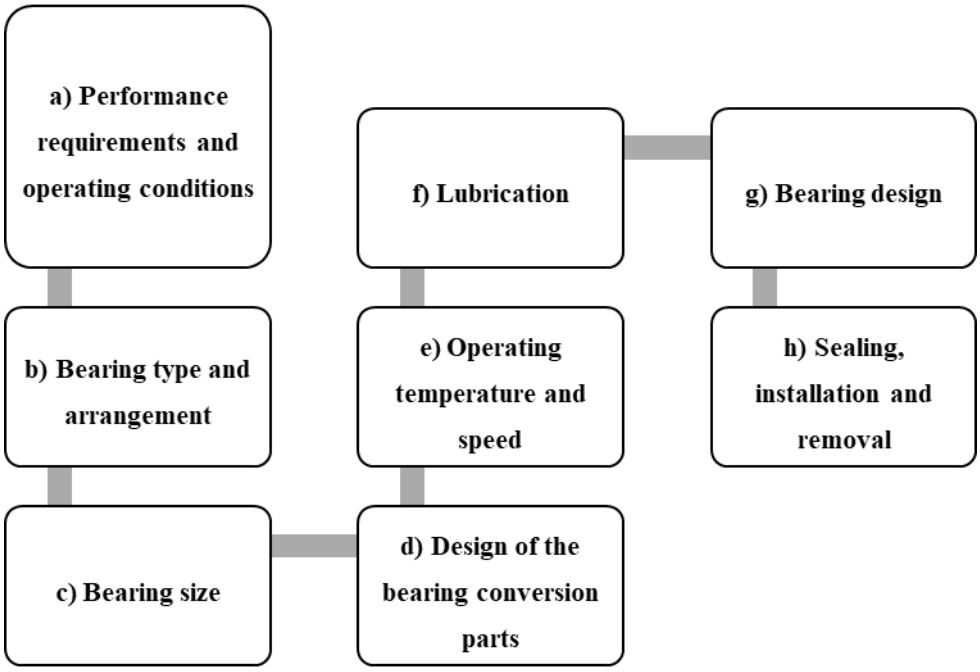
The ISO 80079-36 and -37 standards generally address the basic requirements and protection concepts for mechanical explosion-proof equipment. Specifically, ISO 80079-36 and-37 establish the "procedures for and requirements for the design, construction, testing and marking of non-electrical explosion-proof equipment, explosion-proof components, protective systems, devices and assemblies of these products which have their own potential sources of ignition and are intended for use in potentially explosive atmospheres" (ISO 80079-36).

Rolling bearings are to be understood as Ex components. Although there is no more precise definition of Ex components in the standardization, this can be derived from existing definitions. Thus, a non-electrical device can be defined as: "Device that can mechanically fulfill its intended function" (ISO 80079-36). This means that an Ex-component is a component that "can mechanically fulfill its intended function" and is intended for use in an explosion-protected area.

The ISO 80079-37 considers the design of non-electrical equipment for use in potentially explosive atmospheres. One chapter is devoted to the requirements for rolling bearings.

Derived from the general requirements for devices of the "constructive safety" type of protection according to ISO 80079-37, rolling bearings must be designed for use in potentially explosive atmospheres in accordance with the applicable safety requirements of the applicable industry standards. All operating parameters specified by the manufacturer must be taken into account, including the mechanical and thermal loads to which they are to be subjected. Bearing design requirements by manufacturer using SKF as an example (Figure 2). (SKF) are as follows:

Figure 2. *Bearing Design Process*



Rolling Bearing Design Requirements According to SKF

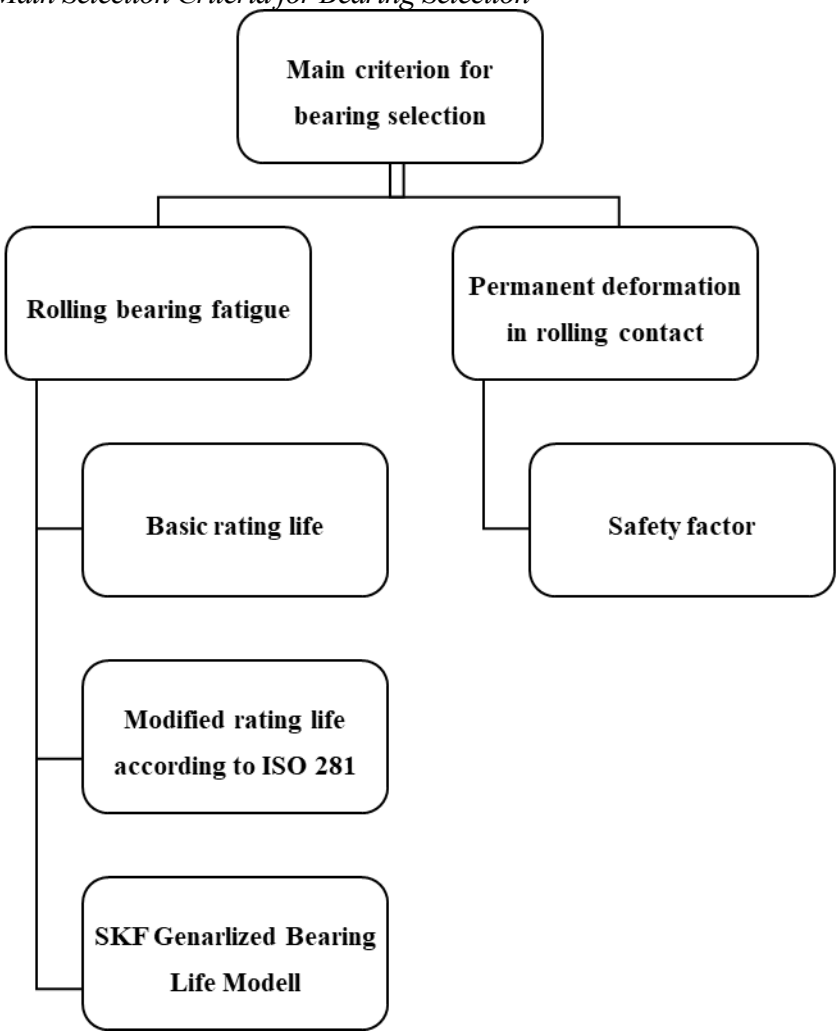
a) First of all, according to the manufacturer, the various operating parameters that influence the selection of the bearing arrangement must be determined. The most important operating parameters are ("Leistungsanforderungen und Betriebsbedingungen | SKF" 2023g):
   - Load,
   - Operating speed,
   - Ambient temperature,
   - Lubricant and lubricant purity.

   Depending on the application, the following factors must also be taken into account in the bearing design. ("Leistungsanforderungen und Betriebsbedingungen | SKF" 2023g):
   - Bearing life,
   - Speed stability and suitability for acceleration,
   - Accuracy of radial and axial position of the shaft and
   - Resistance to low or high temperatures and temperature gradients.

b) Bearing type and their arrangement must be selected in accordance with the expected operating conditions ("Lagerart und Lageranordnung | SKF | SKF" 2023d).
c) The selection of the bearing size can be determined using two different approaches (see Figure 3) ("Lagergröße | SKF | SKF" 2023f):

- Choice of size based on service life or
- Selection of the size based on the static load (via the static safety factor s_0 for the bearing).

Figure 3. *Main Selection Criteria for Bearing Selection*



d) For reliable bearing function, a suitable concept for lubricant supply to the bearings must then be selected on the basis of the operating conditions. The relationship between lubrication and other selection criteria must be taken into account. For example, the lubrication system has a significant influence on bearing life and operating temperature ("Schmierung | SKF | SKF" 2023h).

e) The next step in the design considers the expected operating temperature as well as the allowable speed. There is a complex relationship between temperature and component performance degradation within an application. This relationship has interactions with many other factors, such as bearing sizes, loads, and lubrication conditions. The effects on various performance characteristics within an application and its components are varied and depend on the operating condition, such as at startup or during normal operation in steady state. It is important to predict and test operating temperature and speed

limits. Especially the thermal stability of lubricants plays a decisive role ("Betriebstemperatur und Drehzahl | SKF | SKF" 2023b).

f) After selection and design of the bearing arrangements, the bearing mounting parts must then be designed correctly. Bearing fits on the shaft and in the housing as well as axial securing of the bearings have a major influence on bearing performance. Fits for shafts and housings in rolling bearings are determined using the DIN ISO 286 standard for limiting dimensions and fits ("Gestaltung der Lagerumbauteile | SKF | SKF" 2023c).

g) Furthermore, the following storage properties must be taken into account:
   - of the operating clearance or preload,
   - of the bearing tolerances,
   - of a suitable cage, if necessary and
   - an integrated seal, if required.

   The operating clearance or preload of a bearing in particular has a considerable influence on the running behavior and temperature development during operation ("Lagerausführung | SKF | SKF" 2023e).

h) The last design step according to SKF deals with the selection of external seals, mounting and dismounting as well as inspection and monitoring of the bearings ("Abdichtung, Ein- und Ausbau | SKF | SKF" 2023a).

Rolling Bearing Design Requirements according to International and National Standards

The steps specified by the manufacturer for the design of rolling bearings are supported by a number of international and national (German) standards (Table 8). The following standards must be taken into account in the selection and design of rolling bearings for their use in potentially explosive atmospheres.
In the following, the contents of the standards will be briefly explained.

a) With the help of the ISO 76 he basic static load rating of a rolling bearing can be determined. C_0 can be determined. This is used for the design of rolling bearings which run at very low speeds ($n < 10\ min^{-1}$) (SKF), perform slight swiveling movements or are loaded at standstill. It is defined as a load at which a permanent total deformation of approximately 0.0001 times the rolling element diameter occurs between the points of contact between the rolling elements and the raceway. (ISO 76)
   However, it is often not necessary to calculate the basic static load rating in practice, since this bearing-specific characteristic value is provided by most bearing manufacturers.

b) With the help of ISO 281 it is possible to determine the basic dynamic load rating of a rolling bearing C the basic rating life and the extended rating life according to ISO.
   The basic dynamic load rating is used for the design of rotating and therefore dynamically loaded bearings. The basic dynamic load rating C is the load of

invariable magnitude and direction at which a sufficiently large quantity of identical bearings achieves a nominal life of one million revolutions.
However, it is often not necessary to calculate the basic dynamic load rating in practice, since this bearing-specific characteristic value is provided by most bearing manufacturers.
The basic rating life describes the percentage of an obviously identical bearing group which achieves or even exceeds a certain rating life under identical operating conditions. The probability of achieving the calculated basic rating life is 90%. The basic rating life, given in millions of revolutions L_{10} or operating hours $L_{10}h$ of a rolling bearing is calculated from the equivalent dynamic bearing load, the basic dynamic load rating and the life exponent.
The modified service life calculation L_{nm} extends the nominal service life calculation and includes further influencing factors, such as the experience factor a_1 and the service life coefficient a_{ISO} into the calculation. The service life factor a_1 can be selected according to the operational requirements and increases the statistical probability of survival, depending on the survival factor a_1 from 90% to 99.95% with a simultaneous reduction of the service life. The experience factor is indirectly proportional to the experience probability.
Due to the service life coefficient a_{ISO} the modified service life calculation takes into account L_{nm} takes into account the prevailing operating conditions. This factor takes into account lubricant contamination, the viscosity ratio of the lubricant and the fatigue limit load.

c) ISO 5753-1 Rolling bearings - Internal clearance - Part 1: Radial internal clearance for radial bearings (ISO 5753-1) specifies the values for the radial internal clearance of various bearing types. The values given apply to bearings in unloaded, measurement force-free condition (without elastic deformation).
The bearing clearance is defined as the relative total distance by which the bearing rings (inner and outer ring) can be displaced relative to each other in the radial direction. During operation, it is important that the installed bearing has sufficient internal clearance. It should be noted that the selected fit on the shaft or in the housing may result in a reduction of the bearing clearance during mounting. Likewise, heating during normal operation due to an expansion of the bearing components leads to a further reduction in the internal clearance. These factors must be taken into account when calculating the initial internal clearance according to manufacturer (SKF) must be taken into account. According to the calculated internal clearance, a bearing of the corresponding internal clearance group can be selected in accordance with ISO 5753-1.

d) The ISO 15312 Rolling bearings - Thermal speed rating - Calculation (ISO 15312) provides a calculation basis for the determination of the thermal reference speed $n_{\vartheta r}$. According to ISO 15312 the thermal reference speed describes $n_{\vartheta r}$ describes the speed at which a bearing temperature of 70 °C is reached under reference conditions. The national standard E DIN 732 Rolling bearings - Thermally safe operating speed - Calculation and correction values

(DIN 732) provides a basis for calculating the thermally permissible operating speed n_ϑ. This calculation is based on the frictional power and the resulting heat balance in the rolling bearing. The thermally permissible operating speed n_ϑ is reached when the friction in the rolling bearing generates as much heat as the bearing can dissipate to the adjacent components. The complex calculation of the thermally permissible operating speed n_ϑ often provides results that are closer to reality than the thermal reference speed $n_{\vartheta r}$.

Table 8. *Overview of Standards for the Design of Rolling Bearings*

	ISO standard	Content	DIN standard
a)	ISO 76	Rolling bearings - Static load ratings	DIN ISO 76
b)	ISO 281	Rolling bearings - Dynamic load ratings and rating life	DIN ISO 281
c)	ISO 5753-1	Rolling bearings - Internal clearance - Part 1: Radial internal clearance for radial bearings	DIN 620-4
d)	ISO 15312	Rolling bearings - Thermal speed rating - Calculation	DIN ISO 15312
e)	-	Rolling bearings - Thermally safe operating speed - Calculation and correction values	E DIN 732

Further Requirements According to ISO 80079-37

Certain points of the described design steps according to the manufacturer and the standard are described in ISO 80079-37 and are to be observed according to ISO 80079-37 in the ignition hazard assessment according to 80079-36 special attention must be paid to them. However, the standard only provides information on which aspects must be taken into account in the ignition hazard assessment (examples are shown in Table 9), but does not provide any quantitative characteristic values for the design of the bearings (e.g., experience factor a_1 as a function of the desired level of protection).

According to ISO 80079-37 bearings must always be selected with regard to the task to be performed. According to the standard, the most important factors are "speed, temperature, loading and variations of speed and loading" must be taken into account. In addition, the basic rating life must be determined in accordance with ISO 281. The following are emphasized in ISO 80079-37 the importance of the fit selection with regard to shaft and housing as well as limit deviations, roundness and surface quality of the components surrounding the bearing. The correct alignment of the bearings is also emphasized at this point.

According to ISO 80079-37, attention must be paid to particular attention must be paid to the thermal behavior of adjacent components (shaft and housing) and the resulting additional axial and radial loads on the bearings.

The following must be considered for the ignition hazard assessment the lubrication concept to be used and the protection to prevent the ingress of liquids and solids into the bearing and the lubrication system. According to the standard, a sufficient supply of lubricant must always be ensured.

The bearing and adjacent components must be evaluated for their protection from electrical currents, including stray circulating currents.

In addition, ISO 80079-37 refers to the following refers to the inspection of the specified maintenance intervals and the scheduled replacement of bearings at the end of the recommended calculated service life or after unacceptable wear.

According to standard (ISO 80079-37) bearings must be protected against vibrations, especially in the static state, but also in the dynamic state. The use of non-metallic cages must be avoided. In addition, instructions for the preparation of the operating manual are included.

According to ISO 80079-37, a bearing failure during the period of the nominal life is considered a rare incident. Thus, in the ignition hazard assessment according to ISO 80079-36, bearings are grouped according to EPL Gb/Db without further safety precautions. To achieve EPL Ga/Da, additional ignition source monitoring, e.g. temperature sensor or vibration sensor, is necessary.

Ignition Hazards According to ISO 80079-37

Three potential ignition sources for rolling bearings can be derived from the ISO 80079-37 standard:

a) Hot surfaces,
b) Mechanically generated sparks and
c) Electrostatic discharge.

In normal operation, the ignition sources mentioned above are not to be expected, taking into account correct design, maintenance and installation. For the ignition sources to occur, at least a simple fault must exist. Under this assumption, the incorrect design, mounting or maintenance is already to be regarded as a fault. According to the definition, the bearing is no longer in normal operation. According to the Ordinance on Hazardous Substances, Annex 1, No. 1.7, this is to be understood as the condition in which the equipment is used within its design parameters. Here, the correct bearing design is the standard. If the bearing has an ignition source due to its incorrect design, this condition is not to be interpreted as normal operation. In explosion protection, depending on the intended application zone, the single or rare or double fault case must also be taken into account. This classification is based on the above classification of ignition sources.

Classification of Rolling Bearings for use in Potentially Explosive Atmospheres according to DIN CEN/TR 16829

The DIN CEN/TR 16829 develops protective measures for bucket elevators used to handle flammable products that may contribute to the creation of explosive atmospheres from dust or powder inside the bucket elevator during operation of the bucket elevator. With regard to the ignition hazard assessment of rolling bearings, the standard identifies hot surfaces as a result of bearing damage as a potential direct ignition source. Regarding the initiation of an indirect ignition source, the failure of the bearing is widely considered in the standard. However, this work deals exclusively with direct ignition sources caused by bearings.

Suitable measures to reduce the risk of this ignition source becoming effective are the selection of suitable bearings and materials as well as organizational measures such as shortening maintenance intervals. Temperature monitoring can be used to further reduce the probability of occurrence of this ignition source. When using a temperature unit, over inform about the maintenance and inspection intervals of the additional safety devices in operating or maintenance manuals.

The standard also describes the information to be provided that is relevant for the user with regard to routine inspections, maintenance and cleaning. The user must be informed by means of the operating or maintenance manual that increased attention must be paid to the wear of rolling bearings. In general, the requirements for operating or maintenance manuals are already described in IEC 60079-0 ff and in ISO 80079-36 and -37, but the reference in these standards is not made explicitly to the handling of rolling bearings and their safety components.

In the exemplary ignition hazard assessment for rolling bearings in bucket elevators in DIN CEN/TR 16829 the following measures are introduced to prevent hot surfaces on rolling bearings from becoming effective:

- Measures to avoid arcing and stray currents: Grounding and potential equalization of all conductive elements.
- Bearings are calculated in accordance with ISO 281 for a specific service life. Under these conditions, bearing damage is basically considered a **rare failure**. The highest possible bearing temperature is determined under the most unfavorable conditions (30 °C).

The standard differentiates between internal and external categories when classifying equipment. The ignition hazard assessment carried out refers to the classification of the external device category.

To achieve internal device category 2, the standard also recommends a storage temperature monitor with alarm and emergency stop when a critical limit temperature is exceeded. To prevent an analgesic stop, the standard recommends setting a pre-alarm level.

Table 9. *Ignition Hazard Analysis for Bearings*

No.	1		2					3			4				
	ignition hazard		assessment of the frequency of occurrence without application of an additional measure					measures applied to prevent the ignition source becoming effective			frequency of occurrence incl. measures applied				
	a	b	a	b	c	d	e	a	b	c	a	b	c	d	e
	potential ignition source	description/basic cause	during normal operation	during foreseeable malfunction	during rare malfunction	not relevant	reasons for assessment	description of the measure applied	basis	technical documentation	during normal operation	during foreseeable malfunction	during rare malfunction	not relavant	nacessary restrictions
1	hot surface of a ball bearing as a result of friction	- It is assumed that the temperatures are higher than the ignition temperatures of the product under consideration. - Ingress of dust or water - Loss of lubrication - Excessive axial forces cause damage to the bearings			X		It is assumed that the temperatures are higher than the ignition temperatures of the product under consideration.	- Measures to avoid arcing and stray currents: Grounding and potential equalization of all conductive elements. - Bearings are calculated in accordance with ISO 281 for a specific service life. Under these conditions, bearing damage is basically considered a rare failure. The highest possible bearing temperature is determined under the most unfavorable conditions (30 °C).	ISO 80079-37 "c	Test report on storage temperature has shown that temperatures will not be higher than 40 °C.				X	T4

Source: DIN CEN/TR 16829.

Classification of Rolling Bearings for use in Potentially Explosive Atmospheres in Accordance with DIN EN 14986

The DIN EN 14986 specifies the constructional requirements for fans of group II G (of explosion groups IIA, IIB and hydrogen) categories 1, 2 and 3 and group II D categories 2 and 3 for use in potentially explosive atmospheres. With regard to suitable bearing design, the standard refers to ISO 80079-37.

According to DIN EN 14986, performance data, including the recommended replacement interval for the bearings and seals, must be documented in the operation and maintenance manual. In addition, information on wear and tear must be highlighted. If monitoring equipment is used, e.g. for temperature or vibration monitoring of rolling bearings, these must be checked regularly.

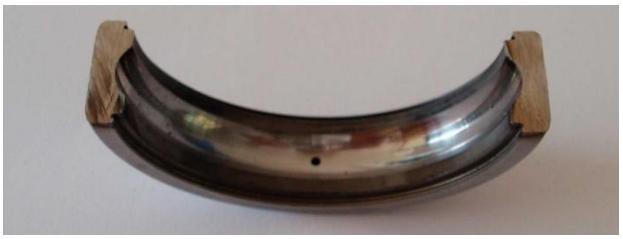
Classification of Rolling Bearings for use in Potentially Explosive Atmospheres According to VDI 2263

The VDI 2263 applies to the assessment of hazards and to measures for the prevention of dust fires and dust explosions including, their dangerous effects. The guideline describes the hazards of different plants with regard to their ignition sources. Rolling bearings are mentioned as a potential ignition source in a large part of the described plants and machines. The general protective measure to prevent the ignition source from becoming effective according to VDI 2263 is temperature monitoring of the bearings. Further measures are not described,

Classification of Rolling Bearings for use in Potentially Explosive Atmospheres in Accordance with Current Publications

Rumbak et al. deals in "Analysis of ignition risk to ball bearings in rotating equipment in explosive atmospheres" (Rumbak et al. 2010) with the effects of damage to ball bearings as an indicator of mechanical ignition sources in rotating machine elements. In the study, temperatures and vibration data of damaged bearings are investigated (Figure 4). The aim is to derive corresponding limit values in order to initiate appropriate countermeasures when impermissible vibrations occur or temperatures.

Figure 4. *Damage to the Outer Ring of Ball Bearing*



Source: Rumbak et al. 2010.

As part of the experimental work, bearings pre-damaged by erosion on the outer ring are examined on a test rig. During the test, vibration and temperature data are recorded.

Table 10. *Time t, min Required to Achieve the Temperature of Each Temperature Class of Ball Bearing with the Damage of the Outer Ring*

Time *t*, (min)					
T6	**T5**	**T4**	**T3**	**T2**	**T1**
85 °C	**100 °C**	**135 °C**	**200 °C**	**300 °C**	**450 °C**
2.02	2.63	3.75	5.21	6.72	8.23

Source: Rumbak et al. 2010.

By analyzing the obtained data, Rumbak et al. derived the time between damage occurrence and the effectiveness of an ignition source to ignite gases and vapors according to their temperature classes (Table 10). In addition, the time between the occurrence of the bearing damage and the temperature for ignition of dust clouds and layers is derived from the data (Table 11).

Table 11. *Time t, min Required to Achieve the Temperature of Ignition of Clouds and Layers of Combustible Dust, Flour and Coal Bearing at Ball with the Damage of the Outer Ring*

Time *t*, (min)			
Layer		**Cloud**	
Wheat flour	**Coal**	**Wheat flour**	**Coal**
230 °C	**350 °C**	**430 °C**	**580 °C**
5.73	7.3	8.06	9.18

Source: Rumbak et al. 2010.

Pieters and Perbal (2011) deal in general with objective risk assessment methods for the use of rotating equipment using a quantitative method. There is a clear description of the boundaries between the different zones expressed in terms of the probability of the presence of an explosive atmosphere. To test the developed method, they use rolling bearings as an example.

Rotating machine elements are discussed in the work of Pieters and Perbal (2011) based on their Frequency of Dangerous failure versus the Duration of effective ignition source with regard to their suitability for use in zones 2 and 1. In the exemplary consideration, a bearing is used which, on the basis of the basic rating life calculation, achieves a running time of 40,000 hours over 20 years under given operating conditions. The relubrication interval is 2,000 hours. The bearings are classified according to the "Ignition Risk Assessment" table developed in the paper as follows:

- Assuming that in the event of a failure of the lubricant supply to a bearing, the bearing temperature rises to a critical temperature range (180 °C) within a very short time (< 60 min) and the lubrication of a bearing cannot be guaranteed by suitable maintenance intervals, the failure of the bearing must be expected within one or less than one year of operation. Bearings under this

assumption may, according to Pieters and Perbal bearings must not be used in potentially explosive atmospheres.

- With regular lubrication, according to Pieters and Perbal the bearing is not expected to fail within 10 years. Taking into account the unchanged duration of effective ignition source (> 60 min), the bearing can therefore be used in zone 2.
- With a suitable maintenance plan and the associated replacement of the bearing before the end of the calculated service life, the probability of bearing failure can be further reduced (<1x/100yr), which means that rolling bearings can also be used in zone 1.
- Use in zone 0 is not considered.

Discussion

Existing literature provides a good overview of the potential ignition sources of rolling bearings.

However, the results of the review do not show a uniform approach to rolling bearing design for their use in potentially explosive atmospheres. Based on ISO 80079-37 "Non-electrical type of protection constructional safety "c", control of ignition sources "b", liquid immersion "k", guidance is given to the designer, but a precise description of the procedure for the design of rolling bearings is not given. The designer is primarily referred to further standards (ISO 281) and manufacturer specifications referred to. If these are followed comprehensively and applied correctly, including all the requirements specified by the manufacturer for the ambient conditions and the observance of maintenance intervals, rolling bearings are suitable for use without further safety precautions in accordance with the standards (DIN CEN/TR 16829.; ISO 80079-37) and are therefore permissible for use in zones 2/22 and 1/21. According to the standard, the occurrence of an ignition source due to rolling bearings is only to be expected in the event of a rare malfunction (DIN CEN/TR 16829.; ISO 80079-37).

In the standard 80079-37 the determination of the service life is based on the nominal service life calculation according to ISO 281, irrespective of the intended level of equipment protection (ISO 281). However, the current standard for rolling bearing calculation is the calculation of the modified rating life in accordance with ISO 281. The calculation of the modified rating life takes into account contemporary bearings of high quality and, under favorable operating conditions, can considerably exceed the calculated values of the basic rating life ("Tragfähigkeit und Lebensdauer | Schaeffler medias" 2023i). For example, a rolling bearing of type 6004-2RSH/VA947 (Forces Radial 1 kN; Forces Axial 0 kN; Speed 3000 r/min; Temperature Inner ring 70 °C; Temperature Outer ring 65 °C; Cleanliness High cleanliness) achieves a rating life according to the basic rating life calculation of L_{10h} 5,470 hours, the service life according to the calculation of the modified service life under favorable operating conditions amounts to L_{nm} 30,000 hours. This corresponds to a factor for life coefficient a_{iso} of 5.48.

In a comparison with the basic rating life (reduction of the modified rating life to 5,470 hours, by changing the service life coefficient a_1), this corresponds, under constant operating conditions, to an equivalent reduction in the service life coefficient a_1 from 1 to approx. 0.19, which in turn increases the lifetime probability from 90% to 99.6%. This significant reduction in service life results in considerable additional expense in the area of maintenance and servicing. At the same time, the service life probability increases significantly.

If, instead of the favorable operating conditions with a high cleanliness of the lubricants L_{nm} instead of the favorable operating conditions with a high cleanliness of the lubricants, the modified rating life is reduced from L_{nm} from 30,000 hours to 2,910 hours. This means that the modified rating life is now only 53% of the basic rating life L_{10h} (5,470 hours) with a service life coefficient of 1. a_{iso} of 1. Based on the service life coefficient a_{iso} of 1, the probability of survival corresponds to 90%. From a statistical point of view, therefore, 10 out of 100 bearings fail before the calculated modified rating life is reached.

When designed in accordance with the standard and manufacturer's specifications and assuming favorable operating conditions, the failure of a bearing can nevertheless be classified as a rare malfunction (ISO 80079-36). However, a deterioration of these operating conditions leads to a significant reduction in the expected bearing service life as well as to a deterioration in the probability of experience. Thus, the simple case of failure (e.g. the failure of a seal) already has a considerable influence on the safety of rolling bearings. According to the standard, no consideration of real operating conditions is provided for in the design of rolling bearings.

For a grouping in the EPL Ga/Da are according to ISO 80079-36 further monitoring devices, such as temperature sensors for ignition source monitoring on rolling bearings, must be provided. A different approach is taken by DIN CEN/TR 16829 follows a different approach in the context of ignition hazard assessment for bearings. According to the standard, rolling bearings are classified in equipment category 1 (equivalent to EPL Ga/Da), taking into account measures to prevent sparkover and stray currents as well as bearing design in accordance with ISO 281 and a calculation of the maximum possible bearing temperature taking into account the operating conditions.

An interesting approach is provided by Rumbak et al. through his investigation of the effect of rolling bearing damage (pitting damage) on the temperature development of the bearings over time. He thus provides a good basis for the design of automatic shutdown systems. It is possible to determine from these results the time remaining after the rolling bearing damage has occurred until a critical temperature limit is reached. Future research could build on these results and investigate further rolling bearing damage.

Conclusions

The overall objective of this paper is to present the current approach to the design of rolling bearings for use in potentially explosive atmospheres. The specific research question is:

> "How should rolling bearings be designed according to the current state of the art for their use in potentially explosive atmospheres?"

In addition, further research approaches will be derived from the current state of the art.

The answer to the research question is developed by means of a systematic literature review. Overall, the literature search shows that the topic described has been dealt with comparatively little in the past.

On the basis of the current standards and their references, this paper can provide an overview of the design steps required for the use of rolling bearings in potentially explosive atmospheres. The various standards are consistent with regard to the measures required for the grouping of rolling bearings with respect to EPL Gb/Db. ISO 80079-36 and DIN CEN/TR 16829 provide a different approach to the grouping of rolling bearings into an EPL Ga/Da.

The various standards all assume favorable operating conditions, which rarely occur in reality, for the design of rolling bearings. In reality, however, a deviation from these favorable conditions results in a considerable deterioration in the service life and the probability of survival. These changes in operating conditions are not considered further in standardization.

Rumbak et al. (2010) provide a promising approach for the thermal behavior of rolling bearings in the event of damage. This can be used as a starting point for further research in this field.

References

Axel Mangelsdorf PW (2019) *Norms and standards for digital transformation: tools, practical examples and decision-making aids for innovative companies, standardisation organisations and political decision-makers.* Berlin: Walter de Gruyter GmbH.

Bartknecht W, Zwahlen G (2013) *Explosion protection: Basics and application.* Berlin: Springer Berlin.

Bearing design | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/bearing-execution.

Bearing size | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/bearing-size.

Bearing type and arrangement | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/bearing-type-and-arrangement.

Cooper HM (1988) Organizing knowledge syntheses: A taxonomy of literature reviews. *Knowledge in Society* 1(1): 104–126.

Design of the bearing conversion parts | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/bearing-interfaces.

DIN 732 (2010-05) *Wälzlager - Thermisch zulässige Betriebsdrehzahl.* (Rolling bearings - Thermally safe operating speed - Calculation and correction values). Berlin: Beuth Verlag GmbH.

DIN CEN/TR 16829 (2019-09) *Brand- und Explosionsschutz für Becherwerke.* (Fire and explosion prevention and protection for bucket elevators; German version). Berlin: Beuth Verlag GmbH.

Eaton's Crouse-Hinds Business (Ed.) (2013) *Explosion protection basics.* Eberbach.

Europäische Union (2014) *Directive 2014/34/EU of the European Parliament and of the Council*. Europäische Union.

IEC, IEC 60079-10-1 *Explosionsgefährdete Bereiche - Teil 10-1: Einteilung der Bereiche - Gasexplosionsgefährdete Bereiche.* (Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres). Berlin: Beuth Verlag GmbH.

IEC, IEC 60079-10-2. *Explosionsgefährdete Bereiche - Teil 10-2: Einteilung der Bereiche - Staubexplosionsgefährdete Bereiche.* (Explosive atmospheres - Part 10-2: Classification of areas - Explosive dust atmospheres). Berlin: Beuth Verlag GmbH.

ISO 76 (2006-05) *Rolling bearings — Static load ratings.* Vernier (CH): ISO

ISO 281 (2007-02) *Rolling bearings — Dynamic load ratings and rating life.* Vernier (CH): ISO

ISO 5753-1 (2009-10) *Rolling bearings — Internal clearance — Part 1: Radial internal clearance for radial bearings.* Vernier (CH): ISO

ISO 80079-36 (2016-02) *Explosive atmospheres — Part 36: Non-electrical equipment for explosive atmospheres — Basic method and requirements.* Vernier (CH): ISO

ISO 80079-37 (2016-02) *Non-electrical equipment for explosive atmospheres — Non-electrical type of protection constructional safety "c", control of ignition sources "b", liquid immersion "k"*. Vernier (CH): ISO

ISO 15312 (2018-2) *Rolling bearings — Thermal speed rating — Calculation*. Vernier (CH): ISO.

Load capacity and service life | Schaeffler medias (2023) Available at: https://medias.schaeffler.de/de/load-carrying-capacity-and-life.

Lubrication | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/lubrication.

Operating temperature and speed | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/operating-temperature-and-speed.

Performance requirements and operating conditions SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/performance-and-operating-conditions.

Pieters P, Perbal R (2011) *Quantative "atex" risk assessment: An alternative method for (parts of) rotating equipment.* Rome, Italy.

Prielipp R, Emanuel C, Wilsky P (2022) *Conducting a Systematic Literature Review in the Engineering Sciences: A Practical Guide.* Technische Universität Chemnitz, Chemnitz.

Rumbak S, Mudronja V, Šakić N, Cajner H, Bogut M (2010) *Analysis of ignition risk to ball bearings in rotating equipment in explosive atmospheres.* PCIC Europe 2010.

Sealing, installation and removal | SKF | SKF (2023) Available at: https://www.skf.com/de/products/rolling-bearings/principles-of-rolling-bearing-selection/bearing-selection-process/sealing-mounting-and-dismounting.

SKF (Ed.) *Rolling bearings.* PUB BU/P1 10000/2 DE No. 2014.

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Optimizing Inception Architectures for Automated Quality Control in Binary Classification

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In computer vision, within convolutional neural network architecture, Inception algorithms play a crucial role for image classification tasks. This study focuses on optimizing Inception architectures for binary classification, particularly for automating quality control processes to simplify control phases and improve accuracy. Conventional quality control methods often rely on manual inspection, which can be time-consuming and prone to human error. The optimization process involves careful consideration of transfer learning methods, the benefits of incorporating fine-tuning and other regularization techniques such as data augmentation, choosing the right values for dropout layers and learning rates will show the best results in terms of accuracy and efficiency. The examination of three different Inception algorithms, Inception v3, Inception Resnet v2, and Xception, reveals that Xception achieves higher validation accuracy 99.72% compared with Inception Resnet V2 and Inception V3 in larger datasets. In the other hand for smaller dataset, Inception V3 achieves higher validation accuracy 99.69% compared with Inception Resnet V2 and Xception. The decision-making regarding the use of these algorithms should be guided by the specific use cases, as each algorithm presents distinct strengths suitable for quality control applications.

Keywords: *CNN, inception algorithms, transfer learning, quality control, image classification*

Introduction

The processing and manufacturing industry has been focusing on enhancing product quality and customer safety through defect detection methods. Manual inspection, commonly used in traditional quality control processes, has limitations such as being time-consuming, prone to human error, and not very efficient. Consequently, there is a growing interest in leveraging advanced machine learning methods, particularly in the realm of computer vision, for automatic quality control (Jing et al. 2020).

To automate the quality control process, the use of Convolutional Neural Networks (CNNs) is deemed to be the most fitting approach due to their superior performance in various image classification tasks. Among the wide array of CNN architectures, Inception-based models have garnered attention for their effectiveness and the ability to capture multi-scale features within images. The original Inception architecture, as well as its subsequent variants such as Inception v3, Inception-ResNet,

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and Xception, have consistently elevated the standards of accuracy and efficiency (Szegedy et al. 2015).

This research is specifically geared toward optimizing Inception architectures for the automated quality control of binary classification problems, aimed at distinguishing defective from non-defective products. Leveraging the power of transfer learning, which facilitates the adaptation of pre-trained models to new tasks, our objective is to fine-tune Inception-based models to achieve high accuracy in defect detection while upholding computational efficiency (Praveen Gujjar et al. 2021). Dataset obtained from Kaggle are used for training and evaluating our models. The dataset was split into training and testing sets approximately (90%/10%) and underwent thorough preprocessing to ensure the robustness of the model.

Starting with a literature review, highlights the recent advancement and applications of Inception algorithms, then the methodology section details the use of Inception V3, Inception Resnet V2 and Xception models and transfer learning techniques. In the results section, it is shown the use of various optimization techniques to identify the best performing model, following with some discussions and conclusions about the insights of selecting optimal algorithm for quality control processes.

Literature Review

The use of Inception architectures in different fields has led to significant progress in image classification tasks. This review discusses recent studies that employ Inception models and related architectures to solve various problems.

A range of machine vision techniques have been researched and applied to automated quality control. For instance, the study by Zhou et al. (2021) achieved an accuracy of 98.50%, while Habibzadeh Motlagh et al. (2018) used pre-trained deep learning models, including ResNet and Inception, for automatic white blood cell classification. This study demonstrates that Inception models deliver high classification accuracy by leveraging their deep feature extraction capabilities. The successful use of Inception models in medical diagnostics suggests their potential for similar critical applications, such as automated quality control in manufacturing. Szegedy et al. (2017) introduced Inception-v4 and Inception-ResNet, highlighting the impact of residual connections on learning. The incorporation of residual connections in Inception architectures represents a significant enhancement, providing a robust framework for tasks requiring high precision. Additionally, Patel and Shah (2023) conducted a comparative study on the early detection of rice diseases using various CNN architectures, including Inception v3, VGG16, VGG19, and ResNet50. The study reinforces the importance of these algorithms in image classification tasks. This comparative analysis underscores the strengths of Inception v3 in handling complex image classification tasks. The paper of Chollet (2017) introduces a novel deep learning architecture that builds upon the Inception model by utilizing depthwise separable convolutions. This approach reduces the number of parameters and computational cost while maintaining model performance. Also, the study by Poojary & Pai (2019) shows a Training accuracy of approximately 99% for ResNet50.

The reviewed literature emphasizes the effectiveness of Inception architectures in various domains, particularly in image classification and feature extraction tasks. The adaptability and robustness of these models make them ideal candidates for automated quality control in manufacturing, where precise defect detection is essential. By harnessing the advanced feature extraction capabilities of Inception models, this research aims to optimize their application in binary classification tasks, contributing to more efficient and reliable quality control processes in industrial settings.

Methodology

Transfer Learning

The Inception algorithms consist of various convolutional neural network (CNN) architectures that have played a significant role in computer vision and deep learning tasks. These architectures are characterized by "Inception modules," which contain convolutional layers with different filter sizes to capture features at multiple scales. In this study, we focus on utilizing Inception V3, Inception-ResNet-V2, and Xception. We conduct our research within the Google Colab environment, which provides GPU capabilities, and utilize the Kaggle Dataset for training and validating our models.

Google Colab offers cloud-based computing power and free GPU resources, making it a preferred choice for deep learning researchers. To get started, users need to create a Google account, upload their dataset into subfolders as specified in the Kaggle dataset, and mount their Google Drive in the Colab environment to enable seamless access to files stored in Google Drive directly from the Colab notebook. Taking advantage of the GPU acceleration feature offered by Google Colab enhances computational capabilities. In this case, we will be using T4 GPU, with GPU RAM of 15.0 GB, System RAM of 51 GB, and Disk space of 201.2 GB. The next step involves installing the necessary libraries and loading pre-trained models. TensorFlow, an open-source machine learning framework, provides a comprehensive ecosystem of tools, libraries, and community resources for building and deploying machine learning models. Keras, an open-source high-level neural network API written in Python, simplifies the process of building, training, and deploying deep learning models by combining the high-level abstractions of Keras with the underlying computational power of TensorFlow.

We load the Pretrained InceptionV3, Inception-ResNet-V2, and Xception models. With a dataset of 7348 images, and a second dataset of 2078 images, transfer learning can be an efficient solution to enable Inception network training without overfitting and convergence problems. This work initializes the Inception and Inception ResNet and Xception convolutional and fully connected layer weights from pre-trained ImageNet models. The InceptionV3 model in tensorflow.keras.applications contains Convolutional blocks, max pooling, activation, batch normalization, and fully connected layers. The architecture of the InceptionV3 model provides a summary of layer names, types, and their connections within the neural network. The InceptionResNetV2 model, available in TensorFlow Keras applications, has a more complex architecture compared to InceptionV3 and includes a combination of Inception modules and residual

connections. The Xception model is an extreme form of an Inception module, almost identical to a depthwise separable convolution, performing spatial convolution independently over each channel of an input, followed by a pointwise convolution.

Based on computational costs for Inception Algorithms, Inception Resnet v2 requires higher computational resources compared with Inception v3 (Korra et al. 2023). In this study we will also compare Xception algorithms, and this can be very helpful in deciding which architecture is better suited for specific image classification tasks.

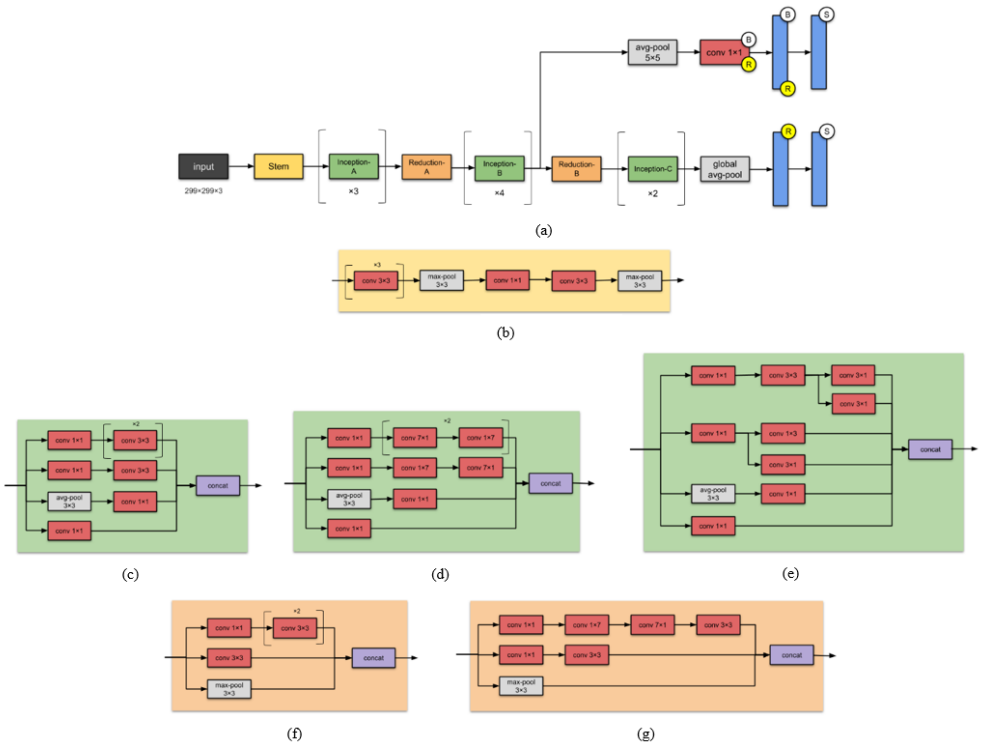
Inception Algorithms Architecture

Convolutional Neural Networks (CNNs) are crucial for image recognition tasks because they can learn spatial hierarchies of features from input images (Fan et al. 2023). They are especially useful for automated quality control systems in manufacturing, where they can identify defects in products. CNNs consist of layers of convolutions, pooling, and fully connected layers, which enable the network to learn complex features. Inception architectures, introduced by Szegedy et al. (2015), represent a significant advancement in CNN design. These architectures incorporate multiple convolutional filters of different sizes in parallel, which allows the network to capture various spatial hierarchies of features simultaneously. This is particularly beneficial for defect detection in manufacturing.

Inception V3 architecture, trained on the ImageNet dataset, uses mathematical operations pooling and convolutions by applying a filter to the input of any layer. Inception V3 is a build-up of the Inception module with multiple filter sizes and then stacks the outputs into one. This allows the detection of objects of different sizes effectively. This architecture also involves reduction modules, which are essentially the same as the inception module but are designed to decrease the dimensions of the input. As described in Figure 1, the input format is 299x299x3, and it goes into the Stem, which has some convolution and max-pooling layers. It is then applied 2x Inception A block, 1x Reduction A, 4x Inception B, 1x Reduction B, and 2x Inception C, global average pooling, Dense layers, and an auxiliary classifier (Korra et al. 2023).

The Inception module is strategically employed to reduce network dimensions. Using 1 × 1 and 3 × 3 convolutional layers, this module effectively minimizes the number of channels and parameters (Fan et al. 2023). Additionally, asymmetrical factorized convolutional neural networks, such as 1x3, 3x1, 1x7, and 7x1 convolution layers, contribute to this dimension reduction. To address convergence challenges in large deep learning layers, an auxiliary classifier is integrated, complemented by average pooling, convolutional 1×1 layers, fully connected layers, and softmax activation, providing a robust solution for the vanishing gradient problem in the final layers (Szegedy et al. 2016).

Figure 1. *Inception V3 Architecture(a), Schematic View of the Stem(b) and Inception A, B, C (c, d, e) and Reduction A, B blocks (f, g)*

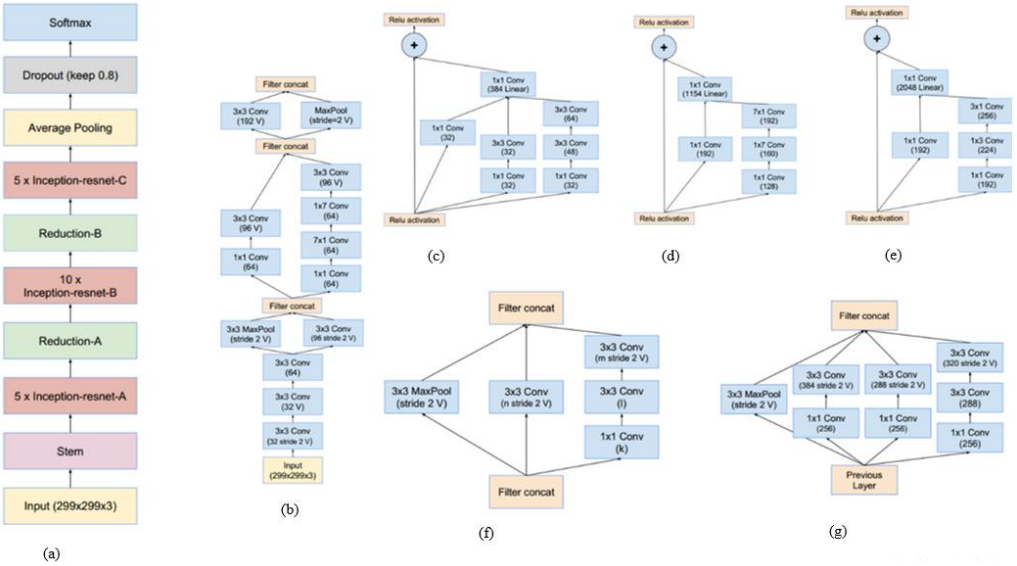


Source: ICITEE 2023.

In 2017, Szegedy et al. introduced the Inception-ResNet, a hybrid model that combines the Inception architecture with residual connections. This unique combination allows the network to benefit from the multi-scale feature extraction of Inception modules while also addressing the vanishing gradient problem through residual connections. The result is a significant improvement in training efficiency and model accuracy, especially in deep networks. In Figure 2, the complexity of the Inception ResNet v2 architecture is shown to exceed that of Inception v3. The layers of Inception ResNet, such as Inception ResNet A, B, and C, are depicted in Figures 2c–2e, with 5, 10, and 5 layers respectively. Additionally, Figures 2f and 2g illustrate the Reduction Layer, Reduction A, and Reduction B. Each Inception block is associated with a filter layer for dimension transformation and input mapping.

In a parallel context, the ResNet architecture addresses the degradation problem by incorporating shortcut connections that create direct paths from shallower sections to deeper networks. This strategy ensures smoother information flow throughout the network. Furthermore, the incorporation of adaptive learning rates, through the Adam optimizer with learning rate 0.001, plays a crucial role in enhancing the efficiency of deep learning concepts. Given the limited size of the available dataset relative to the numerous model parameters, regularization techniques such as dropout and batch normalization are considered essential. These regularization methods contribute to model generalization and stability, ensuring effective training for various scenarios (Poojary & Pai 2019).

Figure 2. *Inception Resnet V2 Architecture (a), Schematic View of the Stem(b), Inception Resnet A, B, C (c, d, e) and Reduction A, B Blocks (f, g)*



Source: AAAI conference on artificial intelligence 2017.

The Xception model, introduced by Chollet (2017), pushes the boundaries of the Inception architecture by replacing standard Inception modules with depthwise separable convolutions. This enhancement results in a more efficient network with fewer parameters and superior performance. Xception has demonstrated outstanding results in image classification tasks, especially in contexts that demand detailed feature extraction. The Xception architecture is a linear stack of depthwise separable convolution layers with residual connections. The network's feature extraction base consists of 36 convolutional layers organized into 14 modules, each with linear residual connections except for the first and last modules. The data first passes through the entry flow, then through the middle flow, which is repeated eight times, and finally through the exit flow.

Optimization Techniques

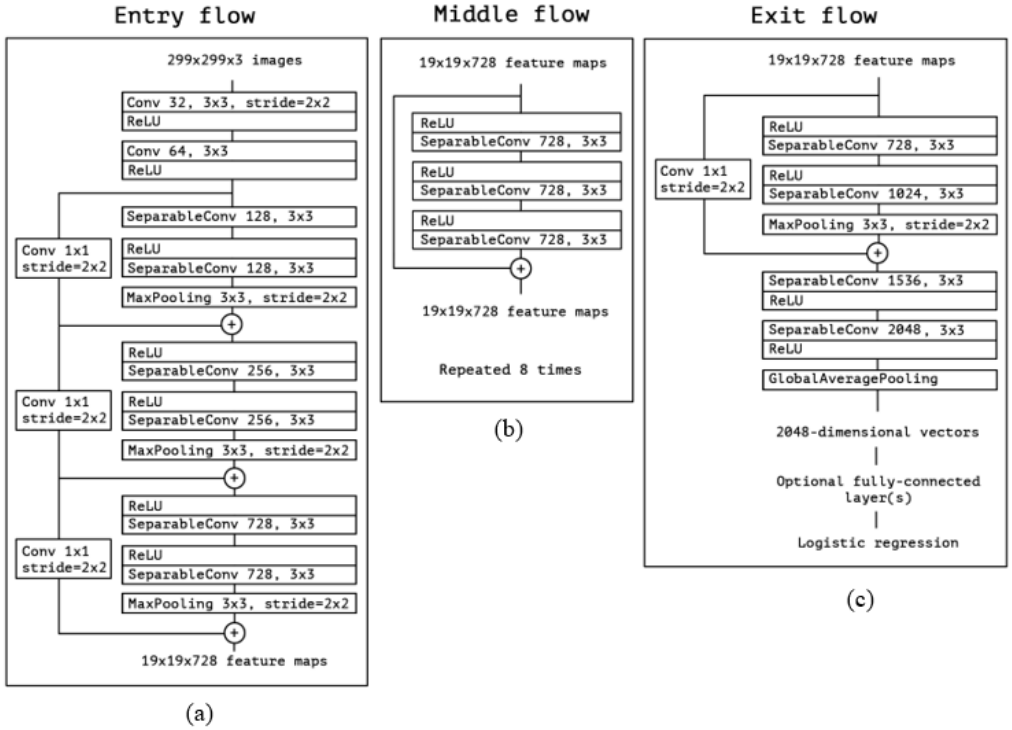
We have leveraged pre-trained models such as Inception V3, Inception ResNet V2, and Xception as the foundation for training our quality control detection model. This method involves utilizing the knowledge obtained from extensive datasets in general image recognition tasks and applying it to quality control detection.

By incorporating transfer learning, we can achieve high precision in our models, even with limited training data and computational resources. Furthermore, we employ optimization techniques to enhance performance, training efficiency, and model robustness. Below are specific techniques that can be implemented for these architectures:

- Learning Rate: Fine-tuning the learning rate is crucial. We will explore the application of values such as 0.001 and 0.0015.

- Dropout: Randomly deactivating units in the dense layers during training to prevent overfitting. Typical dropout rates range from 0.2 to 0.5.

Figure 3. *Xception Architecture Entry Flow(a), Middle Flow (b), Exit Flow (c)*



Source: IEEE Conference on Computer Vision and Pattern Recognition 2017.

Freezing Layers: Freezing the convolutional base of the pre-trained model and only training the dense layers on top.

Data Augmentation: Introducing random rotations up to 20 degrees to make the model orientation-invariant, random zooming in/out by 20% to aid the model in recognizing objects at different scales, and horizontally flipping images to augment the dataset.

In this study it is utilized a pre-trained model (InceptionV3, InceptionResNetV2, or Xception) and frozen its layers to serve as a feature extractor. Following this, I added a dense layer with 256 units, along with a dropout layer and a final dense layer for binary classification. The model was then compiled using the Adam optimizer with a specified learning rate, and its performance was evaluated. By applying these optimization techniques, the model is now better equipped to handle the binary classification task in an automated quality control system achieving an accuracy more than 99.50%. This approach can be adapted and further fine-tuned to meet the specific requirements and constraints of the application. In the context of quality control in manufacturing, the primary objective often involves determining whether a product is defective or not, posing a binary classification problem. Advanced CNN architectures such as Inception V3, Inception-ResNet, and Xception are particularly well-suited for this task due to their capacity to learn complex and detailed feature representations.

This capability is essential for detecting subtle defects that may not be discernible through traditional inspection methods.

Results

A collection of approximately 7348 images (Table 1) and 2076 images (Table 2) was initially obtained from an online machine-learning dataset repository called Kaggle, Casting product image data (Dabhi 2020) and Lemon Quality Dataset (Emir 2022). These images include 'casting product image data for quality inspection, divided into two subfolders train and test with, "ok_front" and "def_front", and Lemon quality respectively "bad_quality" and "good quality". A preprocessing step was executed by the image data generator for training and validation data using the TensorFlow/Keras library. This includes rescale=1./255 normalizes the image pixel values to the range [0, 1] random rotations up to 20 degrees, random zooming in/out by 20%, and horizontally flipping images. Create a generator for training data using the "flow_from_directory" method of the "train_datagen" instance. Resizes the images to the specified target size (299x299), this is often required to match the input size expected by certain deep learning models, such as Inception V3 and Inception-ResNetV2 and Xception in this case. Sets the batch size for training. The model will be updated based on batches of 32 images. Specifies that the task is binary classification. After that, it is needed to create a generator for validation data using a similar approach to the training generator.

Table 1. *Details of Image Dataset as per Classes*

Images	def_front	ok_front	Total test or train
Test	453	262	715
Train	3758	2875	6633
Total	4211	3137	7348

Table 2. *Details of Second Image Dataset as per Classes*

Images	bad_quality	good_quality	Total test or train
Test	95	112	207
Train	856	1013	1869
Total	951	1125	2076

The next step involves setting up a neural network model for binary classification using the InceptionV3 and Inception Resnet v2 and Xception architecture with transfer learning. First, an instance of the Inception model is created with pre-trained weights from ImageNet. The "include_top" parameter is set to "False" to exclude the fully connected layers at the top, and the input shape is specified as (299, 299, 3). All the layers in the pre-trained InceptionV3 model are frozen, which is common practice in transfer learning to keep the pre-trained weights fixed during the initial training.

A Sequential model is initialized, and layers are added to it:

The Flatten layer converts the 2D features from the Xception model into a 1D vector.
A dense layer with 256 units and ReLU activation is added for further learning.
A Dropout layer with a rate of 0.5 is added to prevent overfitting.
Finally, a dense layer with 1 unit and sigmoid activation is added for binary classification.

The model is then compiled with the Adam optimizer (learning rate set to 0.001), binary cross-entropy loss function (suitable for binary classification), and accuracy as the evaluation metric. This code creates a binary classification model based on the InceptionV3, Inception Resnet V2 and Xception architecture using transfer learning, with the pre-trained layers frozen and new layers added on top for the specific binary classification task. The model is compiled for training, with the training process iterating over the entire training dataset 10 times (epochs). We will gather information about the training process, such as the training and validation loss, and accuracy. Detailed information will be shown in the respective tables.

In this study, firstly it is important to choose the right optimization techniques, testing the parameters of dropouts and learning rate. After specifying the optimal parameters, a comparison between Inception V3, Inception Resnet V2 and Xception is defined.

For the first Dataset (7348 images) at Tables 3-5 it is shown that when we increase the dropouts and learning rate the overall accuracy is decreased. The best combination by comparing loss, accuracy, val_loss and val_accuracy in this case is using dropouts 0.2 and learning rate 0.001.

Table 3. *Performance of Xception Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Xception Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	7/10	0.038	0.9863	0.017	0.9972
Dropout 0.5; Learning rate 0.001	9/10	0.0945	0.9603	0.0213	0.9958
Dropout 0.2; Learning rate 0.0015	9/10	0.0524	0.9812	0.0202	0.9958

Table 4. *Performance of Inception Resnet V2 Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Inception Resnet V2 Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	4/10	0.0433	0.9873	0.019	0.9958
Dropout 0.5; Learning rate 0.001	9/10	0.1778	0.9303	0.0235	0.9958
Dropout 0.2; Learning rate 0.0015	9/10	0.061	0.9745	0.0197	0.9958

Table 5. *Performance of Inception V3 Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Inception V3 Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	6/10	0.057	0.9798	0.0197	0.9944
Dropout 0.5; Learning rate 0.001	10/10	0.1132	0.9533	0.0214	0.9944
Dropout 0.2; Learning rate 0.0015	9/10	0.051	0.9806	0.0225	0.9944

Secondly it is needed to compare these algorithms to check which of them is more efficient, while using the optimal dropout and learning rate values.

This information is shown in table 6 where we notice that Xception achieves higher accuracy, followed by Inception Resnet V2 and Inception V3.

Table 6. *Model Comparison Using Optimal Dropout Layers and Learning Rates*

Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Xception	7/10	0.038	0.9863	0.017	0.9972
Inception Resnet V2	4/10	0.0433	0.9873	0.019	0.9958
Inception V3	6/10	0.057	0.9798	0.0197	0.9944

More detailed information for each algorithm is shown at Table 7-9 and Figures 4-6.

Table 7. *Performance of Xception Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	0.9124	0.9279	0.0333	0.9944
2/10	0.0897	0.9717	0.0315	0.9944
3/10	0.0647	0.9775	0.0336	0.9888
4/10	0.072	0.976	0.0568	0.9846
5/10	0.053	0.9837	0.0185	0.9958
6/10	0.0371	0.9872	0.0135	0.9972
7/10	**0.038**	**0.9863**	**0.017**	**0.9972**
8/10	0.037	0.9876	0.0305	0.9944
9/10	0.0477	0.9843	0.0284	0.9888
10/10	0.0353	0.9881	0.0172	0.9958

Figure 4. *(Left) Accuracy Curve and (Right) Loss Curve for Xception Model*

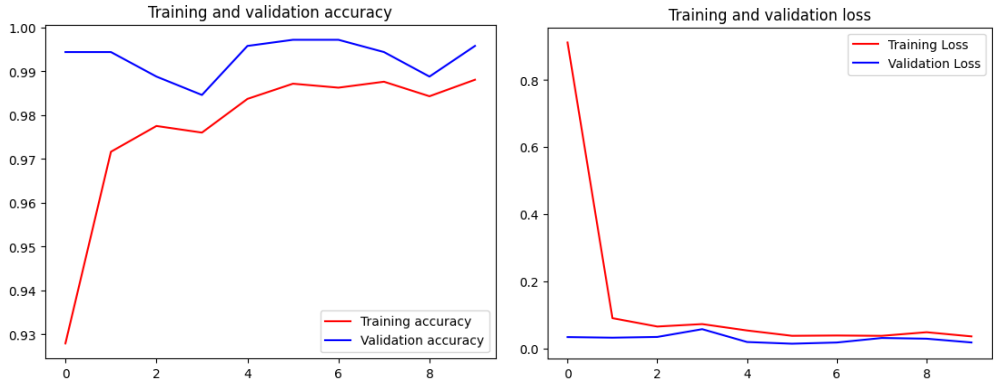


Table 8. *Performance of Inception Resnet V2 Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	1.3467	0.9193	0.0366	0.9902
2/10	0.0659	0.9781	0.0379	0.986
3/10	0.0887	0.9691	0.0375	0.9888
4/10	**0.0433**	**0.9873**	**0.019**	**0.9958**
5/10	0.0555	0.9784	0.0255	0.993
6/10	0.0692	0.9771	0.0494	0.9818
7/10	0.0424	0.9861	0.024	0.993
8/10	0.0328	0.9896	0.0283	0.9888
9/10	0.0307	0.9919	0.0251	0.9902
10/10	0.036	0.989	0.0326	0.9902

Figure 5. *(Left) Accuracy Curve and (Right) Loss Curve for Inception Resnet V2 Model*

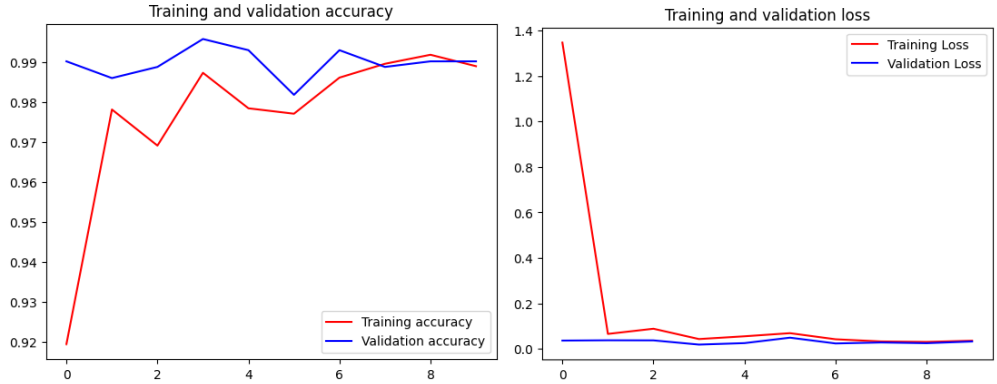
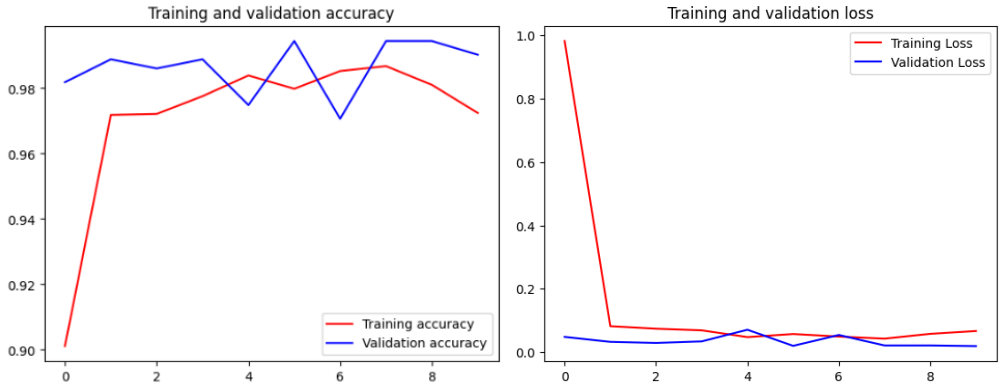


Table 9. *Performance of Inception V3 Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	0.9824	0.9011	0.048	0.9818
2/10	0.0818	0.9718	0.0324	0.9888
3/10	0.0739	0.9721	0.0289	0.986
4/10	0.0688	0.9775	0.0339	0.9888
5/10	0.0473	0.9839	0.0707	0.9748
6/10	**0.057**	**0.9798**	**0.0197**	**0.9944**
7/10	0.049	0.9852	0.0541	0.9706
8/10	0.0425	0.9867	0.0209	0.9944
9/10	0.0576	0.981	0.0209	0.9944
10/10	0.0667	0.9724	0.0189	0.9902

Figure 6. *(Left) Accuracy Curve and (Right) Loss Curve for Inception V3 Model*



It was observed that the Inception V3 algorithm in Google Colab used T4 GPU with 13.7 GB RAM, 5.1 GB System RAM, and 29.0 GB disk space for 15m11s; Inception Resnet V2, 13.7 GB RAM, 5.1 GB System RAM, and 30.0 GB disk space for 15m37s; Xception used 13.7 GB RAM, 4.5 GB System RAM, and 28.1 GB disk space FOR 15m13s. This shows that Inception Resnet v2 requires higher computational resources, and it requires more time.

The same procedure is followed for the second dataset (2078 images). At Tables 10-12 it is shown that when we increase the dropouts and learning rate the overall

accuracy is decreased. The best combination in this case is using dropouts 0.2 and learning rate 0.001.

Table 10. *Performance of Xception Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Xception Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	4/10	0.0792	0.9845	0.1326	0.9855
Dropout 0.5; Learning rate 0.001	10/10	0.0431	0.9818	0.1103	0.9758
Dropout 0.2; Learning rate 0.0015	5/10	0.2124	0.9823	0.1162	0.9807

Table 11. *Performance of Inception Resnet V2 Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Inception Resnet V2 Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	9/10	0.0259	0.992	0.0218	0.9903
Dropout 0.5; Learning rate 0.001	8/10	0.0648	0.9754	0.0446	0.9855
Dropout 0.2; Learning rate 0.0015	10/10	0.0224	0.9914	0.0285	0.9903

Table 12. *Performance of Inception V3 Model Along Evaluation Metrics for the Epoch with Highest Accuracy*

Inception V3 Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Dropout 0.2; Learning rate 0.001	10/10	0.029	0.9893	0.0062	0.9969
Dropout 0.5; Learning rate 0.001	10/10	0.0643	0.9823	0.0184	0.9952
Dropout 0.2; Learning rate 0.0015	9/10	0.0366	0.9888	0.0032	0.9969

Also, it is needed to compare these algorithms to check which of them is more efficient, when using the optimal dropout and learning rate values.

This information is shown in table 13 where we notice that with a smaller dataset Inception V3 achieves higher accuracy, followed by Inception Resnet V2 and Xception model.

Table 13. *Model Comparison Using Optimal Dropout Layers and Learning Rates*

Model	Epoch	Loss	Accuracy	Val_loss	Val_accurancy
Xception	4/10	0.0792	0.9845	0.1326	0.9855
Inception Resnet V2	9/10	0.0259	0.992	0.0218	0.9903
Inception V3	10/10	0.029	0.9893	0.0062	0.9969

More detailed information for each algorithm is shown at Tables 14-16 and Figures 7-9.

Table 14. *Performance of Xception Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	1.2551	0.923	0.606	0.9614
2/10	0.3646	0.9663	0.1715	0.9758
3/10	0.2531	0.9727	0.5258	0.9565
4/10	**0.0792**	**0.9845**	**0.1326**	**0.9855**
5/10	0.0922	0.9818	0.2557	0.971
6/10	0.1447	0.9802	0.259	0.9662
7/10	0.0676	0.9872	0.067	0.9758
8/10	0.0389	0.9866	0.0819	0.9758
9/10	0.0618	0.9829	0.1716	0.9614
10/10	0.038	0.9882	0.0926	0.9758

Figure 7. *(Left) Accuracy Curve and (Right) Loss Curve for Xception Model*

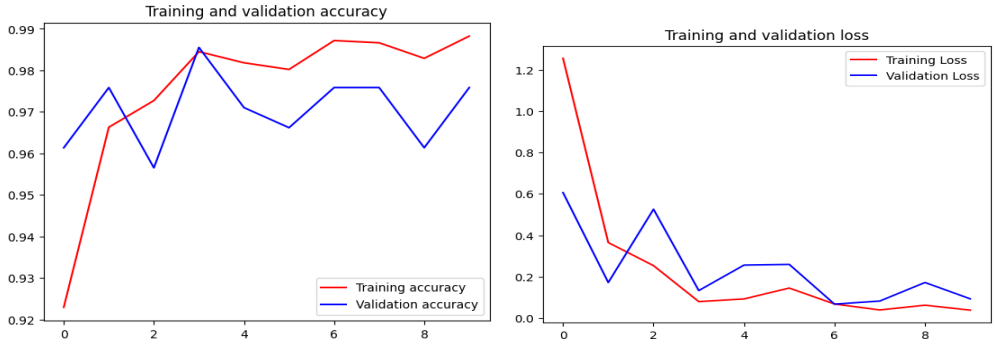


Table 15. *Performance of Inception Resnet V2 Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	1.3621	0.9208	0.2102	0.9565
2/10	0.189	0.9663	0.0418	0.9855
3/10	0.1033	0.9679	0.0543	0.9903
4/10	0.0546	0.9813	0.0559	0.971
5/10	0.0366	0.985	0.0555	0.9807
6/10	0.0447	0.9861	0.0408	0.9807
7/10	0.0403	0.9856	0.0427	0.9855
8/10	0.0425	0.9861	0.0542	0.9807
9/10	**0.0259**	**0.992**	**0.0218**	**0.9903**
10/10	0.0314	0.9872	0.0496	0.9855

Figure 8. *(Left) Accuracy Curve and (Right) Loss Curve for Inception Resnet V2 Model*

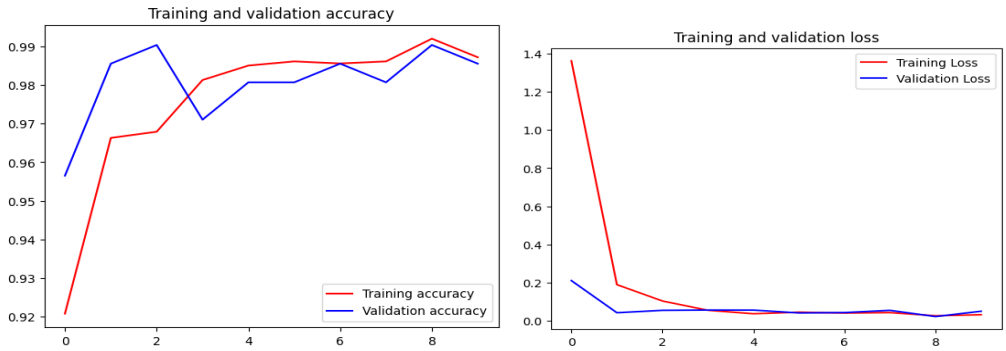
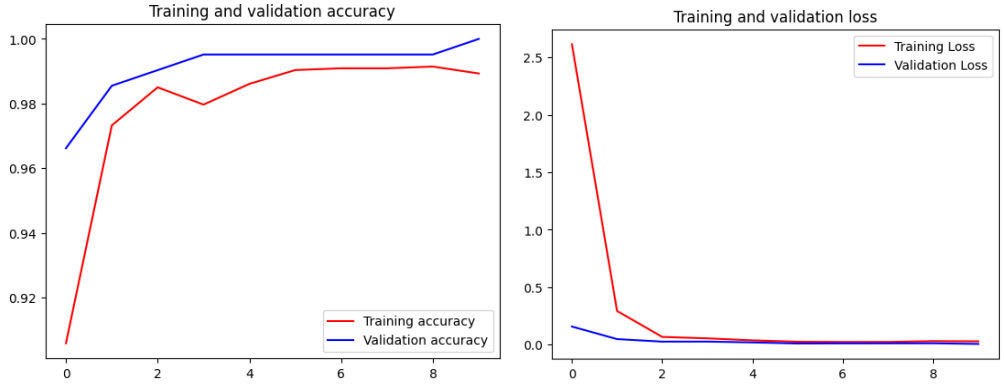


Table 16. *Performance of Inception V3 Model Along Evaluation Metrics for 10 Epochs*

Epoch	Loss	Accuracy	Val_loss	Val_accurancy
1/10	2.6139	0.9058	0.1576	0.9662
2/10	0.2928	0.9732	0.0484	0.9855
3/10	0.0675	0.985	0.0263	0.9903
4/10	0.0549	0.9797	0.0268	0.9952
5/10	0.0376	0.9861	0.0196	0.9952
6/10	0.0253	0.9904	0.01	0.9952
7/10	0.023	0.9909	0.0113	0.9952
8/10	0.0236	0.9909	0.0115	0.9952
9/10	0.0306	0.9914	0.0121	0.9952
10/10	**0.029**	**0.9893**	**0.0062**	**0.9969**

Figure 9. *(Left) Accuracy Curve and (Right) Loss Curve for Inception V3 Model*



It was observed that the Inception V3 algorithm in Google Colab used T4 GPU with 13.7 GB RAM, 6.2 GB System RAM, and 31.8 GB disk space for 4m29s; Inception Resnet V2, 13.7 GB RAM, 6.2 GB System RAM, and 32.1 GB disk space for 4m50s; Xception used 13.7 GB RAM, 6.5 GB System RAM, and 32.8 GB disk space for 4m27s. This shows that Inception V3 model requires lower computational resources.

Discussion

Throughout this research, we delved into the efficacy of optimizing Inception architectures for automated quality control in binary classification within manufacturing industries. Our main aim was to improve the performance of these models in discerning between defective and non-defective products by utilizing advanced data augmentation techniques and parameter optimization.

The findings revealed that through fine-tuning Inception architectures, significant enhancements in model performance were attainable with a value of accuracy, more than 99.50%. Specifically, employing transfer learning with pre-trained Inception models such as InceptionV3 and Xception facilitated robust initial feature extraction, which proved crucial for handling the complexity of the image data in our dataset.

Conclusions

Our research highlights the significant potential of Inception architectures in automating quality control processes in manufacturing industries. Through systematic optimization involving parameter tuning and data augmentation, we were able to greatly improve the performance of these models. Our study reaffirmed the suitability of Inception architectures, especially InceptionV3, Inception Resnet V2 and Xception, for binary classification tasks in quality control, owing to their advanced feature extraction capabilities.

Fine-tuning parameters is critical for achieving optimal model performance. Factors such as the learning rate (0.001), dropout rate (0.2), and dense layer configurations significantly influenced the models' accuracy and generalization. The

use of data augmentation techniques proved crucial in diversifying the training dataset and enhancing the robustness and generalization of the models. Our findings indicated that Xception outperformed Inception Resnet V2 and Inception V3 in terms of validation accuracy, with 99.72% compared to 99.58% and 99.44% of the other respective algorithms in dataset 1. However, it's important to note that in smaller datasets Inception V3 demonstrated a clear advantage in accuracy and computational efficiency. The selection between these models should be driven by the specific requirements of the use case. While Xception offers higher accuracy for large data sets, Inception V3 may be preferable in scenarios with lower dataset where computational resources are a crucial consideration, with an accuracy of 99.69% followed by Inception Resnet V2 99.03% and Xception 98.55%. It's important to evaluate the specific use case and priorities, as each algorithm possesses distinct strengths suitable for various applications.

References

Chollet F (2017) Xception: Deep learning with depthwise separable convolutions. In *2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR),* 1251–1257.

Dabhi R (2020) *Casting product image data for quality inspection*. Kaggle.com.

Emir Y (2022) *Lemon Quality Dataset*. Kaggle.com.

Fan Y, Li J, Bhatti UA, Shao C, Gong C, Cheng J, et al. (2023) A multi-watermarking algorithm for medical images using inception V3 and DCT. *Computers, Materials & Continua* 74(1): 1279–1302.

Habibzadeh Motlagh M, et al. (2018) Automatic White Blood Cell classification using pre-trained deep learning models: ResNet and inception. In *Tenth International Conference on Machine Vision (ICMV 2017),* 1–3.

Jing J, Wang Z, Ratsch M, Zhang H (2020) Mobile-Unet: An efficient convolutional neural network for fabric defect detection. *Textile Research Journal* 92(1–2).

Korra A, et al. (2023) Efficiency and Performance Evaluation of Inception-V3 and Inception-ResNet-V2 in Image Classification. In *ICITEE Conference*, 2–4.

Lemon Quality Dataset (2022) Available at: https://www.kaggle.com/datasets/yusufemir/lemon-quality-dataset.

Patel M, Shah M (2023) Transfer learning with fine-tuned deep CNN model for COVID-19 diagnosis from chest X-ray images. *International Journal of Advanced Technology and Engineering Exploration* 10(103): 720–740.

Poojary R, Pai A (2019) Comparative study of model optimization techniques in fine-tuned CNN Models. In *2019 International Conference on Electrical and Computing Technologies and Applications (ICECTA)*, 1–3.

Praveen Gujjar J, Prasanna Kumar HR, Chiplunkar NN (2021) Image classification and prediction using transfer learning in Colab Notebook. In *Global Transitions Proceedings*, 3–4.

Szegedy C, et al. (2015) Going deeper with convolutions. In *2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 1–3.

Szegedy C, et al. (2016) Rethinking the inception architecture for computer vision. In *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR),* 1–6.

Szegedy C, et al. (2017) Inception-V4, inception-resnet and the impact of residual connections on learning. In *Proceedings of the AAAI Conference on Artificial Intelligence*, 4278–4282.

Zhou, Z, Deng W, Zhu Z, Wang Y, Du J, Liu X (2021) Fabric defect detection based on feature fusion of a convolutional neural network and Optimized Extreme Learning Machine. *Textile Research Journal* 92(7–8): 1–3.

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Motivation in Teaching a Foreign Language in E-learning Environment: Challenges, Perspectives

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The article focuses on the studying of motivation in teaching a foreign language in E-learning environment. The research aimed to analyze digital tools, describe theoretical models, conduct experimental training, and administer surveys. It is based on data obtained from a study conducted at Sevastopol State University. The study included a survey of undergraduate students to identify the factors that contribute to sustainable motivation when teaching a foreign language in E-learning environment. The results of the empirical study revealed varying degree of motivation among 1st year students (45.03.01 "Philology") and 3d year students (44.03.01 "Pedagogical Education") during teaching a foreign language process. The article highlights problems that negatively impact motivation. The authors also emphasize that digitalization of learning is increasingly essential and perceived as necessary by students. Based on the experience of remote learning during the pandemic, the results showed that most students find blended learning to be the most effective format. The authors suggest that the educational system needs to design a new model for organizing the educational process, incorporating advanced technologies and updated pedagogical and methodological solutions.

Keywords: *remote learning, e-learning environment, motivation, learning a foreign language, digitalization of learning*

Introduction

About 10 years have passed since the Russian Federation has implemented digital technologies in all spheres of life. At the international online conference "Artificial Intelligence Journey", the Head of State stressed that "in the coming decade we will have to carry out a digital transformation of the whole country, the whole of Russia, to introduce artificial intelligence technologies, big data analysis everywhere"[1]. It was noted the importance of updating technological progress and the urgent changes in the educational system. According to his statement, the key sources of advanced knowledge are domestic universities.

Artificial intelligence (AI), as a phenomenon, has emerged relatively recently in our lives. Therefore, it requires comprehensive study. In our opinion, new artificial intelligence-based tools such as ChatGPT and Monica are currently opening up new opportunities in higher education for content design, communication, and learning.

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[1]https://aij.ru/.
[2]https://blendedlearning.pro/quarantine/trends_2023/2023-educause/.

This year, the Horizon Report on Teaching and Learning summarizes the results of discussions on the direction in which our future can move. It highlights the following aspects: undergraduates' motivation to continue their studies, universities' digital innovations, and new trends in technologies and educational approaches[2].

Taking personal experience into account, we have identified the challenges of higher education, including remote and hybrid learning formats, the emergence of new forms of teaching and learning at universities, and a new version of "hybrid learning" called HyFlex. Therefore, we need to refine programs, retrain employees, and equip classrooms accordingly. It is important to note that digital technologies do not solve all problems, and the use of artificial intelligence should be considered carefully.

The modern stage is the initial stage of the formation of E-learning environment. In addition, the attitude of students and teachers to the educational process is changing. Having some experience of implementing educational programs using E-learning and distance learning technologies (the lockdown period), the scientists summarize some results, characterizing the positive and negative results of their use.

First of all, the factors which influence the students' motivation to learn a foreign language, including in E-learning environment, whether motivation to learn a foreign language is changing during the transition from traditional learning to learning in E-learning environment.

Secondly, modern society is developing international cooperation, the success of which is closely connected with mastery and the skillful use of foreign language. Thus, the foreign language functions as an instrument of intercultural interaction, ensuring equality of participants in the dialogue.

Nowadays, scholars believe that digital tools, techniques, and media have expanded traditional ideas of knowledge in the arts, humanities, and social sciences. However, it is important to note that student's motivation in digital era is not solely focused on the study of digital culture. Researchers analyze the challenges associated with this field and address questions such as how traditional humanities skills can be adapted to multimedia forms, who will define cultural and historical memory in the digital era, how digital storytelling compares to oral or print-based storytelling, and what role humanities plays in a networked world.

As a result, the transition from traditional teaching methods to communicative-oriented ones aimed at the development of communicative ethics and socio-cultural competence, in our opinion, has significantly expanded the possibilities of foreign language proficiency. In recent years, the high schools have been faced with constantly updated information necessary for the effective learning information technologies of the new generation. However, we notice a gap between the available learning technologies and the expected results for achieving our goals.

According to the results of modern scientific research, the importance of motivation directly affects the effectiveness of professional activity and the ability to achieve these goals.

Although there is a lot of research devoted to motivation, we know not much about learning English online resources and the role of motivation in this process.

Literature Review

The domestic authors (Ilyin 2002, Leontiev 2002, Uznadze 2004, Yakobson 1969) and foreign authors (Adler 2011, Atkinson 2001, Levin 2001, Maslow 2012, Hall 2000) have devoted their research to motivation issues. At the same time, among the academicians there is no single universally recognized theory of motivation which emphasizes the relevance of the analysis and synthesis of existing theories and the practical use of the results obtained in teaching a foreign language process (Samoylenko et al. 2020, Shevchenko et al. 2021).

According to Podlasny, motivation is a common name for processes, methods, means of encouraging students to productive cognitive activity, active development of the content of education (Podlasyi 2004). Zaitsev believes that motivation is an incentive to active activity of individuals, collectives, groups associated with the desire to satisfy certain needs (Zaitsev 2008). Serbinsky defines motivation as the motivation of people to work (Serbinsky 1999). Utkin characterizes motivation as a state of personality that determines the degree of activity and direction of a person's actions in a particular situation (Utkin 2007). Thus, the diversity of definitions of the concept of "motivation", in our opinion, is explained by the multidimensional and interdisciplinary nature of this category. We focus on the opinion of scientists who characterize motivation as a complex, multi-stage system of values, which includes aspirations, desires, feelings, attitudes, ideals, emotions, interests, norms, knowledge, needs, values, etc. (Gez 1985).

Two types of motivation are distinguished: internal, which is related to the person himself, who is able to direct himself to choose/conduct a certain activity, and external, which depends on the factors surrounding the person (Zharko 2023). Modern research highlights that the positive result of learning a foreign language is directly dependent on the motivation of this process. According to scientists, the development of internal motivation is considered one of the most important conditions in the process of learning a foreign language. It is traditionally considered that the student should have a clear idea of their goals and objectives when learning a foreign language, which should be specific, measurable and achievable, so that the student can see their progress in dynamics and feel motivated. The student should be aware of using foreign language not only in his/her professional activities, but also in everyday life.

According to Ugur N.G., the increase in the use of digital technologies has become a phenomenon of the XXI century. The role of these technologies in everyday life and their impact on the future has increased significantly (Ugur 2020).

Zamani emphasizes that the learning environment plays a key role in effective education. The importance of the learning environment is determined by the presence of factors that contribute to active learning and can affect the academic achievements of students (Zamani et al. 2022).

According to Fredy Geovanni Escobar Fandiño, Luz Dary Muñoz, Angela Juliette Silva Velandia "the motivation to learn a foreign language is a complex process" (Fandiño et al. 2020). They analysed undergraduate students' virtual and distance modalities - E-Learning and highlighted the factors for foreign language

learning (intelligence, attitudes, abilities) and the aspects related to the motivation to learn English.

Renzhong Peng and Rongrong Fu have explored the relationship between Chinese English as a foreign language (EFL) students' learning motivation and learning outcomes in a blended learning environment. They have revealed that both intrinsic motivation and extrinsic motivation have a positive relationship with learning outcomes within a blended learning environment (Peng et al. 2021).

As a result of numerous studies, we agree that motivation is a complex psychological process, including cognition, behaviour, emotion, decision-making process and biological aspects.

Foreign languages can be learned at different age levels, in different cultural environments, simultaneously and sequentially.

Problem Statement

The aim of our research is to assess the motivation of the students when teaching a foreign language in E-learning environment of Sevastopol State University (SevSU), using LMS Moodle platform.

The research objectives are:

1) to analyse the process of digitalization of higher education to ensure the effective educational process in new conditions;
2) to describe the educational institutions administration decisions on the organization of training in E-learning environment in the pedagogical and philological areas of training in SevSU;
3) to study the attitude of SevSU students to foreign language learning in E-learning environment and the transformation of motivation in new conditions.

Materials and Methods

The theoretical and empirical research methods were used. The application of theoretical methods allowed for analysis of the digitalization process of higher education to ensure an effective educational process in new conditions. The analysis of publications and academic discussions on the subject was carried out.

The study is based on the results of an empirical study devoted to the analysis of observation and comparison of data obtained through the authors' practice, interviewing university students to understand the problem described. It also comprises the results of conducted survey offered at Sevastopol State University.

The methodological basis of the research is the theory of digital transformation of education. The analysis of psychological, pedagogical and methodological literature on the research topic, analysis of digital tools, theoretical modeling, experimental training, and a survey were used in the research. The instrument we discovered and implemented for English language learning is LMS Moodle. We

designed courses using these tools which provided the structure of educational methods for students. We found a solid rationale for using this platform.

Results

Moving teaching from the current face-to-face model to the online model in response to a global crisis is a necessary solution, but it comes with many challenges. In this research, we indicate these challenges.

In the modern world, not only highly qualified specialists are required, but also flexible professionals who are able to combine knowledge and skills from various fields, as well as quickly adapt to new areas of activity. The main result of higher education should be: the skill of internal persuasion of independent learning, developed system thinking, the ability to adapt. In order to adapt to modern challenges successfully, the Russian educational system should implement a new model of the organization of the educational process based on the use of advanced technologies, updated pedagogical and methodological solutions. This change is called the digital transformation of education.

One of the key goals of digital transformation in the field of education is achieving the necessary educational results by each student. Personalizing the educational process, using the growing potential of digital technologies, such as artificial intelligence, augmented and virtual reality methods are currently implemented. In addition, such transformation promotes E-learning environment implementation and the Internet access, as well as optimal work with large amounts of data. The main task of this transformation is the development and dissemination of an effective model of personalized organization of the educational process, which allows you to achieve great results with optimal resources (Samoylenko et al. 2022).

A number of regulatory documents regulate the activities of educational organizations for the implementation of E-learning environment. As a part of the implementation of the strategic academic leadership program "Priority 2030", Sevastopol State University plans to ensure the integration of the information ecosystem with relevant regional, national and international digital platforms and services. Within the framework of the designated program, it is planned to create digital tools for collaboration in the field of education, scientific research, as well as the economic sector. The online environment will be created for interaction between students, graduates and employers of the region, which will function on the basis of a database of students and graduates, in order to improve the quality of cooperation between the university and business of the Crimea. This will contribute to the successful professional career of the graduate.

In the Russian Federation the requirements of New Federal State Educational Standards of Higher Education 3++ and laws underline the importance of e-learning implementation through Master's Degree Programmes Training[2]. Thus, researchers and educators integrate digital technologies to assist in the teaching and learning process and to design online learning environment at Russian universities.

[3]https://www.sevsu.ru/upload/iblock/23a/xmxtttc1tzzfof1xbjc724775ov58rdz.pdf.

It also leads to the necessity of developing new skills and professional competencies for graduates.

One of the biggest challenges in online teaching is keeping students interested and engaged. There are some challenges: the lack of visibility, which provides immediate feedback to the teacher, requires constant testing and evaluation by the teacher; students get bored and even stressed due to the lack of visual engagement; Basic Competence. Due to the rapid onset of the pandemic, it was impossible to teach the teachers how to effectively develop and utilize distance learning materials (Zharko et al. 2022). The instruments we discovered and implemented for English language learning for undergraduate students is LMS Moodle and Big Blue Button Virtual Room. We designed courses using these tools which provided the structure of educational methods for future teachers. We found a solid rationale for using these two platforms (Samoylenko 2022).

So, the analysis of current scientific research, empirical data and our own pedagogical experience allowed us to identify factors that are aimed at the formation of motivation when teaching a foreign language as shown in Table 1.

Table 1. *Factors aimed at the Formation of Motivation when Teaching a Foreign Language*

№	**Factor**	**Characteristic**
1	The personality of the teacher	* *Moral qualities*: self-discipline, responsibility, ability to manage his/her behavior, objectivity; * *emotional-volitional sphere*: ability to formulate the purpose, emotional skills, perseverance, consistency, individuality, sense of humor, artistic skills; intellectual sphere: broad outlook, high level of intelligence, curiosity; * culture: high level of general culture, culture of speech and communication, sociability, intelligence
2	Teacher's professional skills	* Love to your profession and teaching your discipline; * knowledge of the discipline and methods of its teaching; * teaching skills for creating an emotionally positive psychological climate in the classroom; * the ability to use a system of incentives in the process of learning a foreign language; * constant self-development
3	The social significance of a foreign language	* Knowledge and use of a foreign language in various fields of human activity; * the importance of a foreign language in professional activities; *the students' awareness of the meaning of a foreign language as a means of intercultural communication
4	Modern means of teaching a foreign language	* Selection of interesting authentic material; * the use of information and communication technologies
5	Organization of the learning process	* A skillful combination of traditional and communication-oriented approaches to teaching; * taking into account the individual characteristics of students; * rational use of classroom and autonomous learning; * use of digital tools
6	Ability to learn	* Taking into account the level of linguistic abilities to learn a foreign language; * intellectual abilities; * the personality of the students, their practical orientation.

Thus, we believe that the identified factors are the important conditions for the formation and maintenance of motivation when learning a foreign language. Let's not forget that motivation is an individual factor, and each student can have his/her own motives and ways to maintain motivation. And the task of the teacher is to adapt methodological approaches to the motivation of the student, in order to achieve positive results in learning a foreign language.

In connection with the transition to a personalized educational process, the role of motivation is changing both in the educational process as a whole and in learning foreign languages. External motives, in our opinion, influence educational activities not so effectively. Independence, self-discipline, self-determination (internal motives) of students prevail.

For successful learning in a real or virtual environment, it is necessary to use games (the gamification process), professional cases for learning a foreign language or doing exercises with practical value in real life which are useful for students (Zharko 2023, Samoylenko 2022).

The results of the empirical study revealed a different degree of motivation in the course of teaching a foreign language in E-learning environment of Sevastopol State University among the 1st year students (direction of training 45.03.01 "Philology") and the 3d year students (direction of training 44.03.01 "Pedagogical education") of Sevastopol State University.

Thus, the first-year students noted the increase in interest in learning a foreign language (77%), indicating the following reasons: every time I study something new, I always wonder what will happen next; I begin to understand more; after something inspiring (for example, a lesson); if there is a good teacher (here and further the author's edition of the respondents is preserved). 23% of respondents noted the lack of hours in a foreign language and the quality of their teaching as the reasons that reduced interest in learning a foreign language; after an unsuccessful comment from a teacher; all energy and enthusiasm are taken away by other, less important disciplines; boring presentation of disciplines; lack of opportunity to use the language in practice.

In the third-year students' answers, we found a significant decrease in motivation to learn a foreign language (60%). The respondents noted the complexity of the material; incomprehensible explanation; overload with unnecessary information. 40% of respondents noted an increase in motivation as it is associated with interest, work, moving to another country. As motives that help in learning a foreign language, the respondents of the I, III courses cited the following statements: access to a variety of resources that are not available in their native language; the opportunity to work abroad; immersion in the language system, its history; understanding of symbols; reading in the original; development of intelligence; advantages and increased demand in the labor market; self-development, expanding your horizons; becoming a professional in the professional sphere; teachers who talk with admiration about a foreign language; moving to another country; career development.

Among the factors that influence the increase in motivation in learning foreign languages, the respondents of the I, III courses named: professionally skilled teachers; being in a foreign-language media environment; communication with

people of other cultures; their own desire and desire to learn a language; visiting a country where the language being studied is the national one; understanding the teacher that you need to repeat several times that it is necessary to help and be empathetic to students, to comment about the students' mistakes in an appropriate manner; praise and support of the teacher; the presentation of information is structured and clear; current sources of information; the absence of cases that simply take up your time and do not bring any benefit; interesting approaches to language learning; the lifting of sanctions, the opportunity to be an exchange student; non-boring approach to teaching; teacher's attitude to the language he teaches and methods of teaching; materials.

As a result, we think that in the process of learning a foreign language it is necessary to consider a number of ways that will help increase motivation. They include the use of innovative educational materials, discussion methods and group discussions, the introduction of the latest information reproduction technologies focused on the digitalization of society, as well as role-playing/business games, presentations, project work with continuous updating of the organizational and methodological support of the educational process.

It is very important to mention that the student is a partner in the process of foreign language communication, and maintaining his motivation in an artificially created foreign language environment may present some difficulties. In blended learning, with traditional academic and innovative learning (interactive and electronic), classroom learning technologies and distance learning technologies are used (Leontiev 2002). The educational material is mastered by the graduate student independently in an electronic training course (ETC) with discussion and subsequent consolidation during classroom classes. Electronic educational materials in the ETC are supplemented with hyperlinks and multimedia materials (Samoylenko 2019).

In the learning process a case technology (method) is used. The case method promotes the students' skills development as a result of their independent actions to solve the contradictions that have arisen. When working with cases, students make professional decisions using theoretical knowledge in a specific situation, evaluating and choosing the appropriate option to solve the problem (Samoylenko 2022).

At Sevastopol State University, we try to take into account the request of both the student and the industry. Therefore, one of the ways to be enrolled in a Master's degree is to come up with your project and during training develop the competencies that are necessary for its implementation. To do this, our students are offered individual courses and elective courses, we train tutors and consultants for the students to establish communication, which contributes to the formation of project teams.

For example, a second-year undergraduate student decided to master her skills IN the Digital Humanities program through Internet communications when she realized that she was not only interested in classical translations from English and French, but also wanted to expand her specialization. She enrolled in the master's program after obtaining her bachelor's degree. On one hand, she enjoys her professional activity, but on the other hand, she wants to develop additional competencies. That's why she enrolled in the Digital Humanities program. Now, the

undergraduate student is designing her projects and will also present her research at conferences in the future. It is important for her to understand her abilities and eventually become a product or project manager for her project.

Through this research, we can conclude that the Digital Humanities program is perceived by students as a natural and integral part of globalization. Additionally, Digital Humanities is an interdisciplinary field of research, making it easier to work in this direction for teams that bring together participants with different competencies.

We need to update our class syllabus to include discussions on academic integrity and the use of AI. We discuss academic integrity with our students and when we allow them to use AI, we ask them to share their prompt process with us through screenshots or other means. We also inform our students about the potential inaccuracies of AI and assign them tasks to critically evaluate the accuracy of AI-generated responses. We compare different versions of AI-generated essays or responses in a "peer review" approach. We also utilize AI for our own tasks and planning. We acknowledge the continued growth of AI and the emergence of new resources.

There are many different things to consider when it comes to online teaching: online teaching develops new levels of creativity and opportunity for students, it drives them to surpass themselves and focus more on best practice as well as innovation; students deserve to be taught with 21st-century technology. The teachers can motivate students online through an interactive module of an online course.

Conclusion

In conclusion, several advantages of the educational process in E-learning environment have been identified, including access to a wide range of digital teaching materials, the use of adaptive mechanisms and E-learning platforms, expanded opportunities for creative potential, more effective organization and control of educational activities, mobile communication with teachers through online communities, the active use of innovative learning approaches, the possibility of obtaining online higher education, and the expansion of inclusive education opportunities. However, there are also some disadvantages to E-learning, such as the rapid change of information, the risks of accidents and catastrophes caused by human error, dependence on technical conditions, and the lack of face-to-face interaction between teachers and students.

Remote learning is becoming increasingly important in the global education system and is considered a necessity by students. However, based on the experience of E-learning during the pandemic, most students recognize blended learning as the most effective mode of education.

References

Adler A (2011) *Practice and theory of individual psychology*. M.: Foundation “For Economic Literacy”.

Atkinson JV (2001) *Theory of motivation development*. N.: NORM.

Fandiño FGE, Velandia AJS (2020) How an online tutor motivates E-learning English. *Heliyon* 6(8): 1–7.

Gez NI (1985) Formation of communicative competence as an object of foreign methodological research. *Foreign Language at School* 2: 17–24.

Hall K, Lindsay T (2000) *Theories of personality*. Moscow: EksmoPress.

Ilyin EP (2002) *Motivation and motives*. St. Petersburg: Peter.

Leontiev DA (2002) *Modern psychology of motivation*. M.: Sense.

Levin K (2001) *Dynamic psychology*. M.: Sense.

Maslow A (2012) *Motivation and personality*. St. Petersburg: Peter.

Peng R, Fu R (2021) The effect of Chinese EFL students' learning motivation on learning outcomes within a blended learning environment. *Australasian Journal of Educational Technology* 37(6): 61–74.

Podlasyi IP (2004) *Pedagogy: 100 questions - 100 answers: studies. Handbook for universities*. Moscow: VLADOS-press.

Samoylenko NB (2019) Formation of skills of independent work of students of philology in blended education: advantages, difficulties, prospects. In *Linguocultural education in the system of university training of specialists,* 311–315. Brest, Belarus.

Samoylenko NB (2022) LMS Moodle: training of foreign language teacher at COVID-19 pandemic. *Modern Science* 4(1): 287–290.

Samoylenko NB (2022) Innovative technologies in the professional training of graduates in the digital educational process. In *Innovative pedagogical technologies and strategies in higher professional education,* 182–194. Simferopol.

Samoylenko NB, Zharko LN, Georgiadi AA (2020) Teacher's professional image: reimagining the future. *SHS Web of Conferences* 87: 1–10.

Samoylenko NB, Zharko LN, Glotova AV (2022) Designing Online Learning Environment: ICT Tools and Teaching Strategies. *Athens Journal of Education* 9(1): 49–62.

Serbinsky VY (1999) *Personnel management*. M 201.

Shevchenko MS, Samoylenko NB, Zharko LN (2021) New generation teacher: challenges and technologies. In *European Proceedings of Social and Behavioural Sciences EpSBS* 111: 839–845.

Ugur NG (2020) Digitalization in higher education: A qualitative approach. *International Journal of Technology in Education and Science (IJTES)* 4(1): 18–25.

Utkin EA (2007) *Motivational management*. Moscow: EKMOS.

Uznadze DN (2004) *General psychology*. Translated from Georgian by ES Chomakhidze. St. Petersburg: Peter.

Yakobson PM (1969) *Psychological problems of motivation of human behavior*. Moscow: Prosveshchenie.

Zaitsev GG (2008) *Personnel management at the enterprise: personal management*. St. Petersburg.

Zamani ND, Khalid RM, Shamala P, Aziz NA, Othman D, Whanchit W (2022) Exploring Learning Environment in Online Learning. *International Journal of Academic Research in Business and Social Sciences* 12(10): 585–600.

Zharko LN (2023) Ways to increase motivation in communication-oriented foreign language teaching. Innovative and priority directions in teaching humanities at a technical university. In *Collection of papers based on the materials of the X International Scientific and Practical Conference,* 10–16. Moscow.

Zharko LN, Samoylenko NB, Shevchenko MS (2022) Digitalization of higher education: from theory to practice. *Smart Digital Economy* 2(4): 88–99.