

MACTOR Analysis for Academia-Industry Collaboration in Teaching Metallurgical Processes

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Abstract: This study focuses on analyzing the collaboration between academia and industry in the teaching of metallurgical processes, using the MACTOR technique to investigate the influence and dependency relationships between the different actors involved. Through both an exploratory and descriptive approach, based on an exhaustive review of the literature and consultation with experts, the most significant challenges, strategic objectives, and interdependencies present in this educational and industrial ecosystem are identified.

The analysis allows the actors to be classified according to their degree of influence and dependency, establishing a distinction between those who have a predominant role in decision-making and those who occupy more subordinate or autonomous positions within this collaborative network. The results obtained reveal the main differences and similarities between the various actors, which is key to understanding the opportunities and obstacles that influence the integration of knowledge and technologies in the training of future professionals in the context of metallurgy.

The findings of this study provide insight into the current state of collaboration between academia and industry, which could serve as a reference for decision-making within universities, companies, and regulatory bodies. Understanding these dynamics is essential to strengthen existing alliances and ensure that educational programs are tailored to the needs of the metallurgical sector, thus fostering more relevant and effective training.

1. Introduction

Collaboration between academia and industry is a basic pillar of the development of technical-scientific capabilities in disciplines such as metallurgy (de Mello & Costa, 2023). This cooperation allows for the transfer of knowledge and technology, as well as promoting an appropriate design of educational programs in relation to the particular needs of the labor market and emerging trends in areas such as extractive metallurgy and advanced materials engineering (Amaral et al., 2017).

In recent decades, the link between academia and industry has evolved considerably, in sectors where innovation and technology advance very quickly. According to Mercelis et al. (2017), universities have gone from being fundamental institutions where basic teaching takes place to an organization that has

an important strategic role in technological innovation ecosystems. On the other hand, the metallurgical industry, especially due to its dynamic nature, requires the interrelation between academic training, applied research, and technological development in order to be competitive (Li et al., 2022).

There are examples of collaboration between academia and industry, such as those described by Amaral et al. (2017) in Brazil or those identified by Mercelis et al. (2017) in Europe, which demonstrate the importance of adjusting educational strategies to the regional environment. In metallurgy, the adaptation of this customization includes the use of clean technologies, the development of advanced materials, and theoretical-practical teaching aimed at improving the employability of graduates. Likewise, by establishing this customization, traditional barriers can also be overcome, such as poor communication or different priorities between the actors involved.

In this line, Ortega-Colomer and Pekkola (2018) emphasize the implementation of collaborative systems in higher education as an element that helps create innovation ecosystems in contexts where there is a historical industrial base. One of the prospective analysis tools suitable for this study that deals with collaborative systems is the MACTOR method (Matrix of Actors, Objectives, and Relationships) (Godet, 1991) since it allows for reaching consensus on the objectives of the intervening actors, setting strategic priorities and generating action initiatives that promote both academia and industry practice. Metallurgy, due to its interdisciplinary nature, generally requires practical teaching methods such as teamwork, virtual laboratories, and professional internships (Krishna & Chandra, 2011). In this sense, MACTOR is a correct method to identify the dependency and influence relationships that exist between the actors that manage it, therefore, it explains why MACTOR is considered a method of strategic planning and/or management in complex environments (Godet, 2001). This approach not only identifies the priorities of the actors but also allows the development of training programs that include emerging technologies and sustainable practices.

The application of MACTOR in metallurgical studies is effective since the training needs imposed by the working world can be met with training curricula, as indicated by (Godet, 1986) the MACTOR method has the capacity to prioritize especially those strategic objectives that manage to accommodate technological innovations and the reinforcement of sustainable practices in the training of students, and MACTOR is, therefore, the method that responds to the expectations that the industrial world has towards the academic world, generating a dynamic relationship that allows the adaptation of its way of functioning to face changing contexts.

Based on the above, the purpose of this study is to analyze and interpret how the relationship between education in metallurgical processes and the industrial world can be strengthened through the application of MACTOR. This approach aims to identify who the actors involved are, what the interactions between the different actors are like, and how planning should be organized so that training activities can have an impact on the sector and be relevant to it.

2. Methodology

This research work adopts an exploratory and descriptive approach, as it attempts to show the relationships of dependency and influence that the key actors for the academy-industry collaboration in the teaching of metallurgical processes have with each other, in order to detect areas of collaboration and areas of conflict or possible conflict. Exploratory research allows the detection of variables of interest and initial patterns that can be further explored in subsequent studies (Swedberg, 2020). On the other hand, descriptive research is aimed at describing phenomena, populations, or other situations in a precise manner, that is, it presents detailed and exhaustive information on the main elements that compose them (Siedlecki, 2020).

In this sense, this work focuses on analyzing the links between academic, industrial, and government institutions that contribute to the development and teaching of metallurgical processes. The research has a qualitative approach because it is aimed at understanding the complex relationships that actors have in a given context. As Herrera (2017) maintains, the qualitative approach is ideal for exploring complex dynamics and thoroughly studying the phenomena under study.

This paper uses a non-experimental and cross-sectional design, that is, the variables have not been manipulated nor have interventions been carried out, but the relationships have been observed and analyzed as they are presented at a given time (Frölich et al., 2014). As suggested by (Sampieri, 2018), a cross-sectional design is suitable for analyzing phenomena at a given point in time, which is also the case in the current situation of the metallurgical sector.

The actors participating in the research were chosen intentionally based on their importance and the role they play in the collaboration between academia and industry. The target group was made up of, among others, universities and research centers that carry out teaching and innovation programs in metallurgy; and companies that develop metallurgical processes such as the production of steel and aluminum. In order to identify the main actors, a very exhaustive literature review was carried out and 15 semi-structured interviews were held with experts in the sector selected for their experience and the importance they have in educational and collaborative processes in metallurgy.

For the analysis, the MACTOR method was used, which has been recognized as a very effective tool in strategic foresight for mapping and analyzing the existing interactions between actors. First, the strategic objectives of the different actors were established, taking into account emerging technologies, sustainable practices, and applied research. Later, influence and dependency matrices were constructed that reflected the relationships between the actors. The previous analysis allowed the identification of direct and indirect interactions, generating a map with more detail of the functioning of the set of actors. Likewise, the actor-by-actor matrix was used to characterize the shared and divergent objectives, which is key in identifying the potential for cooperation and conflicts.

3. Results

This section presents the results of the exploration of the current context of the metallurgical sector, with a focus on the identification of key actors and the dynamics of their interactions. Based on the literature review, a list of relevant actors was obtained, which is detailed in Table 1. This table is organized into three columns: the first assigns a unique code to each actor to facilitate their reference within the study, the second column indicates the name of the actor and the third describes their role within the system analyzed.

For example, the actor identified with code A1 corresponds to Universities and research centers, whose main role is to design academic programs in metallurgy, carry out applied research, and develop technological innovations for the sector. Similarly, actor A2 refers to Companies in the metallurgical sector, which play an essential role in the implementation of technological advances in metal production processes, in addition to collaborating with universities in the technical training of future professionals and generating employment in the sector.

This organization allows for observing the different actors and their respective contributions within the metallurgical ecosystem, facilitating the analysis of influences and dependencies that will be developed in the following sections.

Table 1. List of actors identified in academia-industry collaboration in the metallurgical sector

Code	Actor	Role
A1	Universities and research centers	Design academic programs in metallurgy, conduct applied research, and develop technological innovations for the sector.
A2	Companies in the metallurgical sector	Implement technological advances in metal production processes, collaborate with universities in technical training, and generate employment in the sector.
A3	Governmental and regulatory entities	Establish regulations on sustainability, education, and industrial processes, as well as finance academic-industry collaboration initiatives.
A4	Industry associations	Facilitate communication between companies and universities, promote quality standards, and encourage innovation in the metallurgical industry.
A5	International organizations	Establish global guidelines and certifications for sustainable metallurgical processes and good practices in technical education.
A6	Technical and vocational educational institutions	Train specialized technicians in metallurgical processes, ensuring that graduates have skills aligned with the demands of the sector.
A7	Companies in technologies applied to metallurgy	Develop innovative solutions for the automation, digitalization, and optimization of metallurgical processes.
A8	Experts and consultants in metallurgy	Provide advice on research, innovation, and best practices to improve the competitiveness of the sector.
A9	Investors and innovation funds	Finance startups, R&D projects and new technologies applied to metallurgy.
A10	Trade unions and labor organizations	Defend the rights of metallurgical workers and participate in the definition of job training programs.
A11	Recycling and circular economy companies	Promote sustainable practices in the metallurgical working industry by recycling materials and reducing environmental impact.

Source: Authors

Similarly, the list of objectives that were defined from the literature review and the consultation of experts in the metallurgical sector was obtained, which is included in Table 2.

Table 2. List of objectives of the actors identified in the metallurgical sector

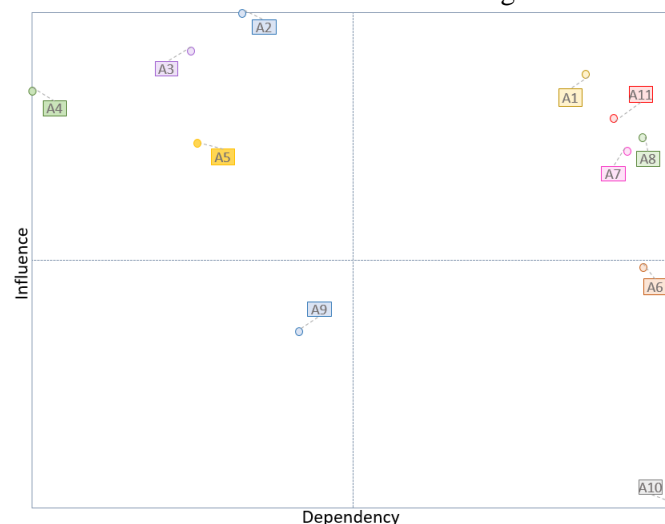
Code	Objective
O1	To strengthen academic and technical training in metallurgy to improve the employability of graduates.
O2	To promote technological innovation in metal production and transformation processes.
O3	To promote sustainability in the metallurgical industry through circular economy practices and emission reduction.
O4	To improve collaboration between universities, companies, and government agencies for the development of joint projects.
O5	To ensure alignment between educational plans and the needs of the labor market in the metallurgical sector.
O6	To develop new technologies for the automation and digitalization of metallurgical processes.
O7	To promote public policies that encourage technical education and applied research in metallurgy.
O8	To increase investment in research and development (R&D) within the metallurgical industry.
O9	To ensure compliance with environmental and safety regulations in metallurgical production.
O10	To improve the transfer of knowledge between academia and industry to accelerate the adoption of innovations.
O11	To reduce dependency on foreign technologies by developing national capabilities in advanced metallurgy.
O12	To encourage the continuous training of professionals in the sector to maintain global competitiveness.
O13	To ensure the availability of critical and strategic materials for industrial development.

Source: Authors

This information was then entered into the MACTOR software to create the influence matrices and the matrix of valued positions, allowing the identification of the strategic relationships between the actors and the key objectives of the study. Once the data collected was analyzed, the actors were classified into four types, as presented in Figure 1. The dominant actors are characterized by their ability to influence others, while the dominated ones depend on others to achieve their objectives. The autonomous ones, on the other hand, operate independently and have little influence and dependency, while the linking actors act as a connection point between the different elements of the network. The classification of actors allows for understanding part of the power dynamics and the opportunities for collaboration that exist between academia and the metallurgical sector.

As can be seen in Figure 1, the dominant actors are: companies in the metallurgical sector (A2), government agencies (A3), industrial associations (A4), and international organizations (A5). They have the greatest influence on the system; the linking actors are universities (A1), companies in technologies applied to metallurgy (A7), experts and consultants (A8), and recycling and circular economy companies (A11). These actors mediate between innovation, regulation, and the needs of the sector. The dominated actors are technical educational institutions (A6), trade unions and labor organizations (A10), as they depend on the most influential actors to implement changes. Finally, only one actor was classified as autonomous: investors and innovation funds.

Figure 1. Plane of influence and dependency positions of the actors in the academia-industry collaboration network in the metallurgical sector

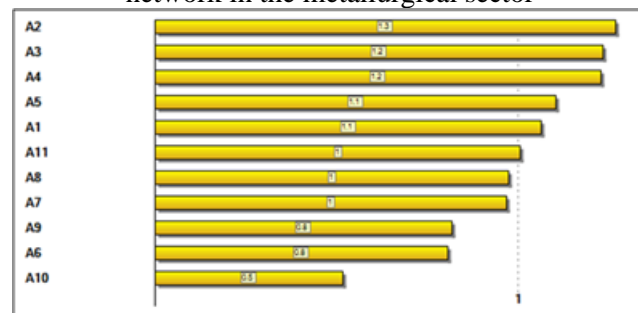


Source: Authors

Strength relationships of each of the actors in the academy-industry collaboration network in the metallurgical sector

Once the actors were classified, the strength relationships of the different actors were evaluated using the strength relationships histogram generated by the MACTOR software. As shown in Figure 2, the results show that the actors with the greatest strength are A2, A3, A4, A5, and A1. The actors with intermediate strength relationships are A11, A8, and A7. The actors with the lowest strength were A9, A6, and A10.

Figure 2. Histogram of the strength relationships of the actors in the academia-industry collaboration network in the metallurgical sector



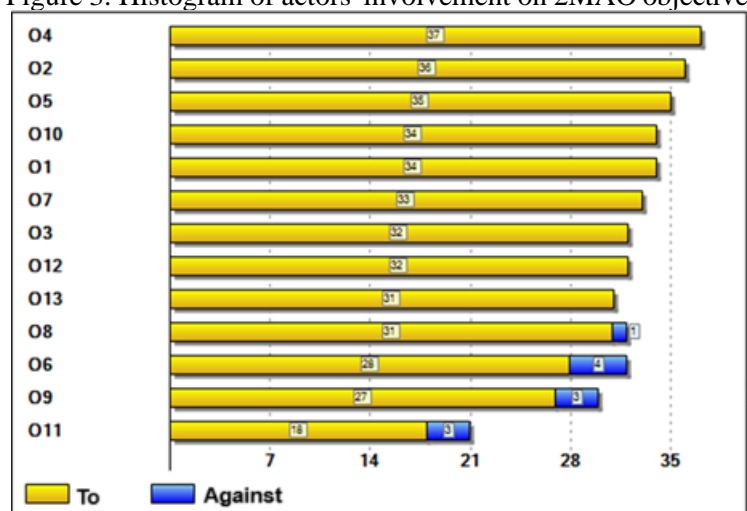
Source: Authors

Positioning of actors in relation to the objectives

The next step in the analysis is to determine the position of the actors concerning the defined objectives, which can be visualized through the histogram of the actors' involvement with the second-order objectives (2MAO). In this histogram, represented in Figure 3, the different levels of commitment of each actor with respect to the strategic objectives in the object of study can be observed.

The histogram in Figure 3 (level of actor's commitment) shows that there is a high level of actor's commitment to achieve objectives O4, O2, and O5. Similarly, there is a medium level of actor's commitment to achieve objectives O10, O1, O7, O3, and O12. And there is a low level of actor's commitment to meet objectives O13, O8, O6, O9, and O11.

Figure 3. Histogram of actors' involvement on 2MAO objectives



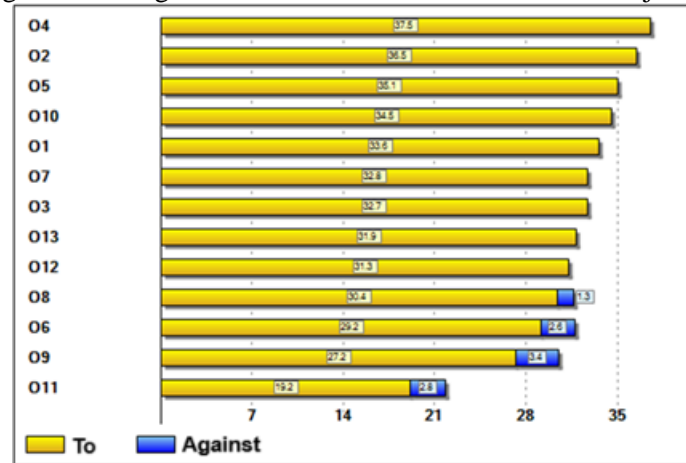
Source: Authors

On the other hand, the histogram of the actors' involvement in the objectives of order 3 (3MAO), illustrated in Figure 4, allows for analyzing the capacity of action of each actor in relation to the established objectives. The combination of these results enables the construction of a commitment and capacity matrix, which facilitates the identification of the most viable objectives to achieve based on the level of involvement of the actors in the academia-industry collaboration, as well as their real capacity to influence its achievement within the metallurgical sector.

Finally, the data collected through the analysis were interpreted and validated through a feedback process with the experts interviewed. Thanks to this step, the conclusions were precise, relevant, and closely aligned with the needs of the metallurgical sector as they are today. Furthermore, the results obtained were compared with the existing literature in order to strengthen the validity of the analysis. This treatment of the data offered a rich and consistent basis for the identification of collaborative strategies that could be put into practice and be productive at a general level.

In this sense, the histogram in Figure 4 (capacity of the actors to act concerning objectives) shows a high capacity of the actors to achieve objectives O4, O2, and O5. Likewise, a medium capacity is observed to achieve objectives O10, O1, O7, and O3. While a low capacity is observed for objectives O13, O12, O8, O6, O9, and O11.

Figure 4. Histogram of actors' mobilization on 3MAO objectives



Source: Authors

Convergences and divergences between actors

This analysis allows for identifying both convergences and divergences between the actors involved in the academia-industry collaboration within the metallurgical sector. To do so, the 1CAA convergence matrices and the order 2 convergence graph (2CAA) are used, which allow for visualizing the degree of alignment between the actors concerning the strategic objectives of the study.

Figure 5 presents the order 1 convergence matrix (1CAA), which shows which actors have the highest coincidence in their interests. The actors with the highest cumulative convergence are A3, A4, A5, A6, A8, and A11, with a value of 123 each. This result suggests that these actors could form a strong collaborative group since their objectives are highly aligned with the other actors in the system. Likewise, actors with a lower overall convergence within the system were identified, including A2 and A9, with a value of 107 and 109 respectively. This lower convergence may indicate that these actors have a higher level of autonomy or that their interests are less aligned with those of others. As a consequence, they could experience difficulties in fully integrating into joint initiatives or representing independent positions within the network.

Figure 5. Matrix of convergence between actors of order 1 (1CAA)

A/A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
A1	0	10	12	12	12	12	11	12	10	13	12
A2	10	0	11	11	11	11	10	11	11	10	11
A3	12	11	0	13	13	13	12	13	11	12	13
A4	12	11	13	0	13	13	12	13	11	12	13
A5	12	11	13	13	0	13	12	13	11	12	13
A6	12	11	13	13	13	0	12	13	11	12	13
A7	11	10	12	12	12	12	0	12	12	11	12
A8	12	11	13	13	13	13	12	0	11	12	13
A9	10	11	11	11	11	11	12	11	0	10	11
A10	13	10	12	12	12	12	11	12	10	0	12
A11	12	11	13	13	13	13	12	13	11	12	0
N. C.	116	107	123	123	123	123	116	123	109	116	123

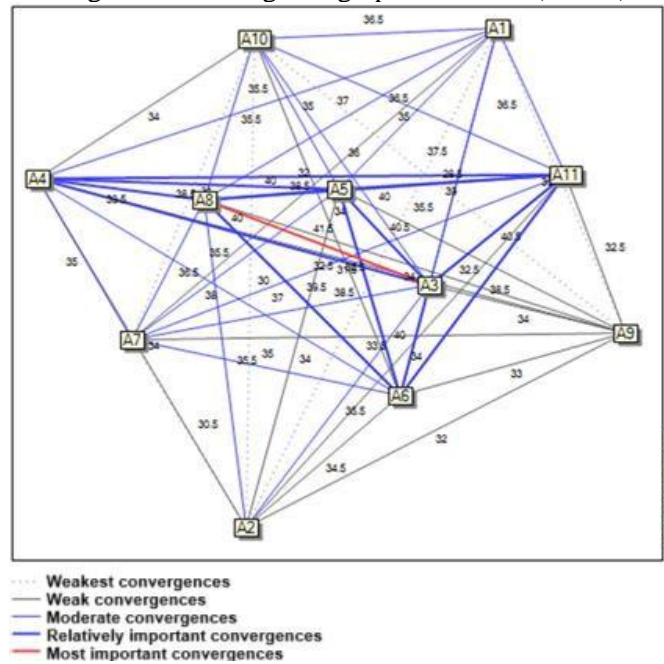
Source: Authors

Unlike the 1CAA matrix, which measures the number of possible alliances between actors, the graph in Figure 6 allows for analyzing the intensity and strength of these alliances, considering the relative weight of the objectives shared by each pair of actors within the study system.

In the graphical representation, the strongest convergences are highlighted in red, while the relatively important ones are shown in blue with a thick line. Moderate convergences appear in blue with a thinner line, weak convergences in solid black, and finally, the most fragile ones are represented with black dashed lines.

As can be seen in Figure 6, the most significant convergence is between actors A8 and A3, which confirms the results obtained in the matrix 1CAA, where the possibility of a strategic alliance between these actors was evident. This relationship indicates that they share key objectives within the academia-industry collaboration in metallurgy, which could favor the development of joint initiatives within the sector.

Figure 6. Convergence graph of order 2 (2CAA)

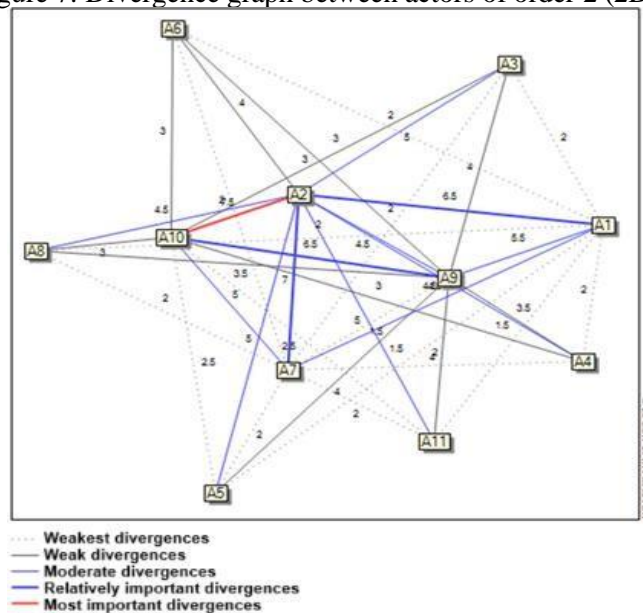


Source: Authors

Regarding divergences between actors, the graph of order 2 divergences (2DAA), represented in Figure 7, shows the intensity of conflicts based on the relative importance of the objectives that each pair of actors shares within the metallurgical sector. In this graph, the most intense divergences are highlighted in red, while those with less impact appear in progressively fainter shades.

As can be seen in Figure 7, the most intense divergence of order 2 occurs between actors A2 (Companies in the Metallurgical Sector) and A10 (Trade Unions and Labor Organizations). In addition, three relatively important divergences were identified, between A2 (Companies in the metallurgical sector) and A1 (Universities and research centers), A9 (Investors and innovation funds) and A10 (Trade Unions and Labor Organizations), as well as between A2 and A7 (Companies in technology applied to metallurgy). These conflicts reflect the current challenges in the collaboration between academia and industry for the teaching of metallurgical processes, where it is necessary to find balance points between technological innovation, employability, and the adaptation of educational programs to the needs of the sector without compromising the stability of workers or slowing down the adoption of new methodologies.

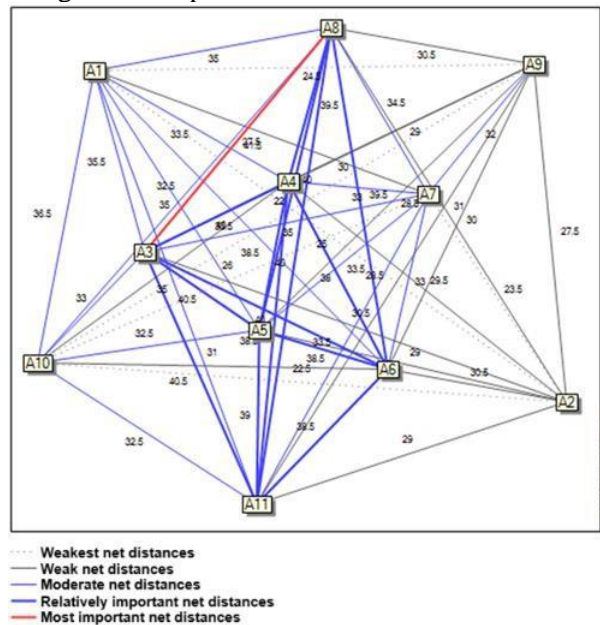
Figure 7. Divergence graph between actors of order 2 (2DAA)



Source: Authors

Once the convergences and divergences between the different actors in the academia-industry collaboration in the teaching of metallurgical processes have been identified, it is possible to analyze the potential alliances and existing challenges using the net distance graph, represented in Figure 8. This graph makes it possible to visualize which actors have the greatest difficulties in aligning themselves based on their interests and objectives, which can influence the effectiveness of cooperation in the sector. As seen in Figure 8, the most critical gap, represented in red, occurs between actors A3 (Government and regulatory entities) and A8 (Metalworking experts and consultants). This gap reflects a key discrepancy in how educational policies and technological advances in the sector are conceived and implemented. In addition to this critical gap, other important discrepancies were identified between different actors, which shows the existence of additional challenges in the alignment of interests within the sector.

Figure 8. Graph of net distances between actors



Source: Authors

4. Discussions

The results of the study show several critical and divergent relationships between the key actors in the academia-industry collaboration in the teaching of metallurgical processes. Significant differences were identified between A3 (Government and regulatory entities) and A8 (Experts and consultants in metallurgy), which highlights the challenges in aligning educational policies with the needs of the sector. Likewise, other relevant divergences were detected between A2 (Companies in the metallurgical sector) and A1 (Universities and research centers), A9 (Investors and innovation funds) and A10 (Trade unions and labor organizations), as well as between A2 and A7 (Companies in technology applied to metallurgy). The discrepancies described determine the effectiveness of reinforcement strategies in metallurgical education and may contribute to the existence of dysfunction between academic training and the demands of the working world.

In this way, the divergence of A2 in relation to A1 is determined by the distance that exists between the demands of the business world and the academic approach to teaching education in metallurgy since companies usually request graduates with practical skills, knowledge related to new technologies, and a faster adaptation to current industrial processes, while universities prioritize having a more theoretical and research perspective, which provides a very uneven balance in the approach between education and the demands of the sector.

Fundamental divergences in academic-business collaboration

The most important divergences are found in three fundamental areas: the adaptation of the study plans, the adaptation of new technologies for teaching, and the impact that automation has on employment. These tensions can lead to an inability to adapt educational programs to the parameters of the sector and impact the modernization of teaching in metallurgy.

In particular, the contrast between A3 (Government entities) and A8 (Metalworking experts and consultants) shows the tension between the regulation of education and the need to modernize curricula. According to Drinkwater (2016), the lack of alignment between universities and the sector in the training of metalworking processes results in an inability of graduates to integrate into the sector. This is in line with the findings of Bhullar et al. (2017), who highlight that many educational institutions still operate under traditional models that do not respond to current technological demands.

On the other hand, the conflict between A9 (Investors) and A10 (Trade Unions and Labor Organizations) is linked to investment in automation and its impact on employment. While investors seek to maximize efficiency through digitalization and robotization, trade unions fear that these advances will lead to a significant reduction in jobs. Studies such as the one carried out by Focacci y Perez (2022) emphasize that innovations in metallurgy, while necessary for competitiveness, must be accompanied by ongoing training programs to avoid job displacement.

Furthermore, the divergence between A2 (Companies in the metallurgical sector) and A7 (Companies in technology applied to metallurgy) arises from the resistance of some companies to adopt emerging technologies in metallurgical training. While technology companies promote the use of simulations, virtual laboratories, and advanced software for teaching, many metallurgical companies consider that traditional practical training remains more effective. According to Scandura and Iammarino (2022), the integration of new technologies in technical education must rest on an adequate practice between theory and practice, as well as cooperation between the educational sector and the industrial sector.

Critical distances are also evident between actors A3 (Government and regulatory entities) and A8 (consultants and experts in metallurgy). This distance highlights a critical need. While A3 prioritizes producing regulatory frameworks and public policies with a generalist approach to training in metallurgy, A8 tends to focus its attention on the specific needs of the sector and the integration of new methodologies that are probably not fully covered by current regulations (Antonazzo et al., 2023). This distance suggests the need to take care of communication between these actors, creating mechanisms for better flexibility between updating training plans and ownership of emerging technologies without falling into contradiction with regulations.

From a theoretical perspective, these results show the need to focus on academia-industry collaboration in metallurgical education as a complex system where the dynamic relationship of the different actors demonstrates the capacity of the educational system to adapt to the demands of the sector. Along these lines, the literature recommends that network and resource dependency theories can enrich the analysis of relationships; not only the influences of regulators and universities must be taken into account, but also the impact of industry, investors, and trade unions (Drinkwater, 2016).

In practice, the results of this study are useful for establishing more structured collaboration strategies that allow for reducing conflict between regulators, universities, and companies. For example, the dual training model widely used in Germany was effective for training metallurgical engineers, integrating periods of apprenticeship in companies with academic learning, and achieving a better adjustment to the labor market in a consensual way (Dudyrev et al., 2018).

Despite its relevance, this study has certain limitations that should be considered when interpreting its results. First, the methodology implemented is based on a static network analysis, which makes it difficult to capture the changing dynamics in the interactions between actors over time. Second, the focus is on a specific group of participants, which could have excluded some significant interactions from the analysis. Finally, educational regulations and collaboration structures in the metallurgical sector vary across countries, which could restrict the possibility of generalizing the findings globally. Future research could address these limitations by exploring how dependency and influence relationships between actors evolve in different national contexts. It would also be valuable to analyze the collaboration between academia and industry in the teaching of metallurgical processes, especially under conditions of accelerated change, such as the transition to Industry 4.0. Furthermore, the use of temporal analysis could facilitate the identification of how collaboration dynamics change in response to emerging demands of the sector, providing a more complete view of the interaction between universities, industries, and regulators in the training of future metallurgical professionals.

This study reinforces the need to strengthen collaboration between academia and industry in metallurgical education, addressing crucial divergences such as the modernization of curricula, the incorporation of new technologies, and the relationship between automation and employment. Through more structured cooperation and the adoption of successful models such as dual education, it is possible

to mitigate these tensions and improve the preparation of professionals in accordance with the demands of the sector.

5. Conclusions

The analysis of the collaboration between academia and industry in the teaching of metallurgical processes using the MACTOR technique has allowed for identifying both the key actors and the strategic interactions between them, providing a deeper insight into the dynamics, convergences, and tensions that characterize this relationship. This approach has allowed not only the mapping of the influence and dependency of each actor within the educational-industrial ecosystem but also the evaluation of the degree of support or opposition of each one towards specific strategic objectives in the training of future professionals in metallurgy.

The results indicate that the lowest convergences were found between actors A3 (Government and regulatory entities) and A8 (Experts and consultants in metallurgy), A3 and A7 (Companies in technology applied to metallurgy), A8 and A7, as well as A3 and A1 (Universities and Research Centers). These low convergences reflect the difficulty of aligning educational policies with the technological and innovation needs of the industry, which may limit the modernization of academic programs in metallurgy.

On the other hand, the most intense divergences were identified between actors A2 (Companies in the metallurgical sector) and A1 (Universities and research centers), A2 and A10 (Trade unions and labor organizations), A2 and A7 (Companies in technology applied to metallurgy), A3 and A8, A9 (Investors and innovation funds) and A10, among others. These divergences reflect conflicts around the adoption of new technologies in teaching, the updating of study plans, and the impact of automation on job stability.

The findings of this study provide a solid foundation for future research that examines how these dynamics evolve over time and what strategies can be implemented to strengthen collaboration between universities, companies, and regulators in the field of metallurgical training.

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