Dynamic Social Network Analysis of Metaverse Communities Using Temporal Graph Modeling and Louvain Community Detection Algorithm

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ABSTRACT

The strategic transition toward the metaverse represents a major organizational and technological transformation for digital platform firms. This study examines how such a transformation is reflected in the structural evolution of corporate communication networks. Using quarterly earnings call transcripts of Meta from Q3_2018 to Q3_2025, we construct temporal analyst–executive interaction graphs and apply dynamic social network analysis combined with the Louvain community detection algorithm. The findings reveal persistent but fluctuating community clustering, a gradual increase in network density, and alternating phases of structural reorganization and consolidation. Centrality analysis demonstrates a clear transition from CFO-centered communication dominance to increasing CEO centralization in later periods. The Community Stability Index further indicates that early transformation phases involve structural adjustments, followed by greater persistence as strategic direction matures. These results provide quantitative evidence that large-scale metaverse transformation is accompanied by measurable restructuring in governance communication networks. The study contributes to understanding how immersive digital transformation reshapes organizational structures, executive influence distribution, and platform governance dynamics.

Keywords Metaverse Transformation, Dynamic Social Network Analysis, Louvain Community Detection, Corporate Communication Networks, Executive Centralization

INTRODUCTION

The metaverse has emerged as a transformative paradigm within digital platform ecosystems, integrating immersive technologies such as virtual reality, augmented reality, and persistent virtual environments into interconnected socio-economic infrastructures [1], [2]. Beyond its technological dimension, the metaverse represents a large-scale strategic and organizational transformation for firms investing in immersive digital futures [3]. For platform-based corporations, the transition toward the metaverse involves not only infrastructure development but also governance restructuring, leadership repositioning, and communication realignment [4].

Meta Platforms provides a prominent case of such transformation. Following its strategic rebranding in 2021, the company redirected substantial investments toward immersive technologies and virtual ecosystem development [5]. While prior studies on the metaverse primarily focus on technological architecture, user experience design, blockchain integration, or digital asset economies [6], [7], considerably less attention has been paid to organizational restructuring during metaverse transition phases. In particular, the relational and communicative dimensions of corporate governance during large-scale digital transformation remain underexplored [8].

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Recent research in digital platform governance emphasizes the importance of communication networks in shaping strategic alignment and leadership authority [9]. Organizational network theory further suggests that structural changes in communication patterns often accompany technological and strategic shifts [10], [11]. Dynamic social network analysis has been increasingly applied to study evolving relational structures in innovation ecosystems [12], yet its application to corporate governance networks during metaverse transformation remains limited. Existing studies typically analyze static network configurations or focus on external user communities rather than internal executive–stakeholder interaction dynamics [13].

This reveals a critical research gap. First, there is limited empirical evidence on how metaverse transformation affects corporate communication structures over time [14]. Second, few studies employ temporal graph modeling to capture community evolution and leadership centralization during strategic technological pivots [15]. Third, the interplay between executive dominance, community clustering, and structural stability in platform governance networks remains insufficiently quantified [16].

To address this gap, the present study models the temporal evolution of executive–analyst interaction networks during Meta's strategic transition toward the metaverse. Using quarterly earnings call transcripts from Q3_2018 to Q3_2025, we construct dynamic interaction graphs and apply Louvain community detection to examine clustering patterns, modularity evolution, density changes, community stability, and leadership centralization. By integrating temporal social network analysis with community detection techniques, this research provides quantitative insight into how immersive digital transformation reshapes governance communication structures.

Through this approach, the study contributes to advancing the state of the art in metaverse research by extending the focus beyond technological infrastructure toward relational governance dynamics. It demonstrates that metaverse transformation is not solely a technological shift but also a structural reconfiguration of organizational communication networks and executive influence distribution.

Literature Review

The concept of the metaverse has evolved from speculative virtual environments into a strategic framework for immersive digital ecosystems [17], [18]. Recent literature defines the metaverse as an interconnected, persistent virtual space integrating virtual reality, augmented reality, blockchain systems, and digital economies [19], [20]. Scholars highlight its potential to reshape digital interaction, economic models, and platform governance structures [21], [22]. However, much of the existing research remains technologically oriented, emphasizing infrastructure, interoperability, and immersive user experience [23].

Parallel to technological discussions, digital platform governance research examines how platform firms structure authority, coordination, and communication during large-scale transformation [24], [25]. Governance in digital ecosystems involves not only technological control but also relational alignment among stakeholders [26]. Communication networks, particularly those involving executive leadership and financial stakeholders, play a crucial role in shaping strategic narratives and reinforcing institutional legitimacy [27].

Organizational network theory provides a foundational lens for understanding structural change in communication systems [28]. Network structures influence information diffusion, leadership influence, and strategic coordination [29]. Studies show that during periods of innovation or strategic uncertainty, organizational networks often undergo reconfiguration, resulting in shifts in centralization, clustering, and influence distribution [30]. Centralization, in particular, has been associated with decision-making concentration during high-risk transformation phases [31].

Dynamic social network analysis extends traditional static network approaches by modeling structural evolution over time [32]. Temporal graph modeling enables researchers to observe how communities form, dissolve, and stabilize across different phases of organizational change [33]. Community detection algorithms such as Louvain modularity optimization are widely applied to identify cohesive clusters within complex networks [34]. These techniques have been used in innovation networks, knowledge diffusion studies, and digital ecosystems, yet their application to corporate governance communication during metaverse transition remains limited [35].

Existing studies on executive communication networks largely focus on board interlocks, leadership collaboration, or social media engagement [36]. Few studies examine structured executive–analyst interaction networks derived from earnings calls, and even fewer analyze their temporal evolution during strategic technological pivots [37]. As a result, the relational dimension of corporate transformation toward immersive digital environments remains insufficiently quantified.

The current state of the art therefore, presents two primary limitations. First, metaverse research predominantly emphasizes technological infrastructure rather than organizational structural change. Second, dynamic network methodologies have not been extensively integrated into platform governance analysis during digital transformation [32], [35]. This creates a gap in understanding how immersive strategic pivots reshape communication centralization, community formation, and leadership dominance over time.

By integrating temporal social network analysis with Louvain community detection in the context of executive–analyst communication, the present study advances the literature in three ways. It extends metaverse scholarship into the domain of organizational governance structures, applies dynamic graph modeling to corporate strategic transformation, and provides empirical evidence linking technological pivot phases with measurable network restructuring.

Methods

This study employs a dynamic social network analysis framework to model the structural evolution of executive–analyst interaction networks during Meta's strategic transition toward the metaverse. The methodological process consists of data preparation, temporal graph construction, community detection, and longitudinal structural measurement. The dataset is derived from quarterly earnings call transcripts spanning from Q3_2018 to Q3_2025. Each record represents a question–answer interaction between a financial analyst and a company executive. Table 1 summarizes the key characteristics of the dataset.

Table 1 Dataset Description

Component	Description

Data Source	Meta Earnings Call Q&A
Time Span	Q3_2018 – Q3_2025
Number of Quarters	29
Total Analysts	29
Total Records	275
Network Type	Bipartite Undirected Network
Temporal Unit	Quarterly Snapshot

The dataset consists of 29 quarterly snapshots containing 275 interaction records. A total of 29 unique analysts appear across the observation period. The network is modeled as a bipartite undirected graph in which analysts and executives constitute two distinct node sets connected through Q&A interactions. Each quarter is treated as an independent temporal snapshot to enable longitudinal structural comparison. The overall research procedure is illustrated in figure 1.

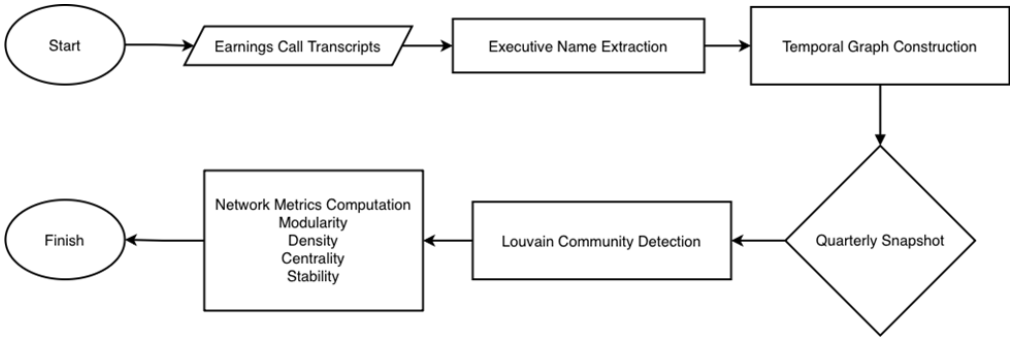


Figure 1 Research Framework

The research framework begins with raw earnings call transcript collection. Executive identities are extracted from structured Q&A responses to construct analyst–executive interaction pairs. For each quarter, a temporal graph is generated in which nodes represent analysts and executives, and edges represent Q&A interactions. Community detection is then performed using the Louvain algorithm, followed by computation of structural metrics including modularity, density, stability, and centrality measures. Finally, temporal comparison across snapshots is conducted to assess structural evolution during the metaverse transformation period. Table 2 presents the graph construction and analytical parameters applied in this study.

Table 2 Graph Construction Parameters

Parameter	Value
Node Types	Analyst, Executive
Edge Definition	Q&A Interaction
Temporal Modeling	Snapshot-based Dynamic Network
Community Detection Algorithm	Louvain Algorithm
Optimization Objective	Modularity Maximization
Graph Layout	Spring Layout

Community structures are detected using the Louvain algorithm, which maximizes modularity to identify cohesive clusters within each quarterly

network. This algorithm is selected due to its computational efficiency and robustness in detecting community structures in medium-scale networks. To evaluate structural evolution, multiple network metrics are computed for each snapshot. Modularity measures clustering intensity, network density captures overall connectivity, the Community Stability Index evaluates persistence of node membership across consecutive quarters, and degree, betweenness, and eigenvector centrality quantify executive prominence and brokerage roles. Temporal analysis is conducted by arranging snapshots chronologically and comparing structural metrics across adjacent quarters. This dynamic approach enables systematic examination of how immersive digital transformation reshapes governance communication networks over time.

Result

Descriptive Network Statistics

Table 3 presents the structural characteristics of the quarterly analyst–executive interaction networks from Q3_2018 to Q3_2025. Across the observation period, the number of nodes ranges from 9 to 17 per quarter, while the number of edges varies between 9 and 23. Community detection using the Louvain algorithm identifies between 2 and 4 communities per snapshot. Modularity values fluctuate between 0.0799 and 0.4017, indicating moderate but persistent community clustering. The highest modularity value is observed in Q4_2019 (0.4017), suggesting peak structural fragmentation during that quarter. Conversely, Q2_2025 exhibits one of the lowest modularity scores (0.0799), reflecting a more centralized communication structure.

Table 3 Network Statistics per Quarter

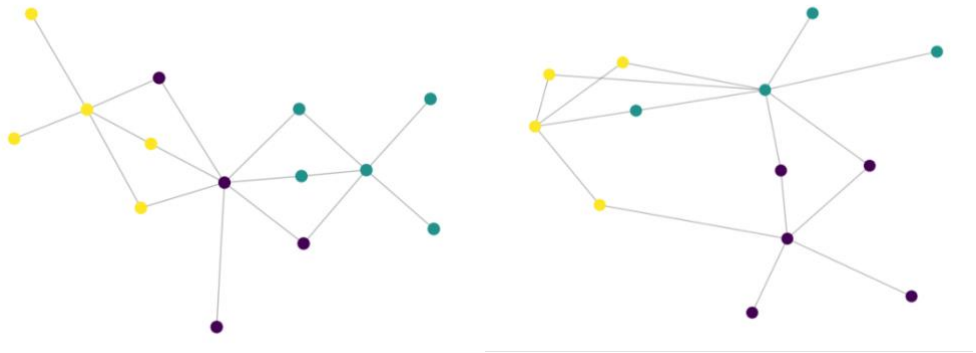
Quarter	Nodes	Edges	Communities	Modularity
Q3_2018	14	17	3	0.3131
Q4_2018	15	23	3	0.1871
Q1_2019	16	20	3	0.3162
Q2_2019	16	21	3	0.2812
Q3_2019	14	18	3	0.2361
Q4_2019	17	19	3	0.4017
Q1_2020	11	13	3	0.2101
Q2_2020	12	16	2	0.2637
Q3_2020	12	17	2	0.2422
Q4_2020	11	14	3	0.2372
Q1_2021	12	14	3	0.2730
Q2_2021	14	17	3	0.3097
Q3_2021	13	18	3	0.2222
Q4_2021	12	16	2	0.2500
Q1_2022	13	16	3	0.2910
Q2_2022	12	14	3	0.3036
Q3_2022	12	15	4	0.2800
Q4_2022	13	18	3	0.2207
Q1_2023	11	12	2	0.2188
Q2_2023	9	11	2	0.1322

Q3_2023	9	9	2	0.2716
Q4_2023	9	11	2	0.1322
Q1_2024	11	13	2	0.3140
Q2_2024	11	12	2	0.2465
Q3_2024	0	0	0	0.0000
Q4_2024	10	13	2	0.1154
Q1_2025	11	13	2	0.1893
Q2_2025	9	12	2	0.0799
Q3_2025	12	13	2	0.2692

Table 3 reveals several important structural patterns. First, network size remains relatively stable across quarters, with only moderate fluctuations in the number of participating analysts and executives. The temporary absence of interactions in Q3_2024 likely reflects missing transcript data rather than structural collapse. Second, the number of detected communities decreases after 2022, stabilizing predominantly at two communities per quarter. This reduction in community count suggests gradual consolidation of interaction clusters during the later stages of Meta's strategic transition toward the metaverse. Third, modularity values indicate that while community structures persist throughout the study period, the degree of fragmentation varies. The pronounced peak in Q4_2019 suggests a temporary intensification of segmentation, whereas lower modularity values observed in 2024–2025 reflect increased centralization and reduced structural fragmentation. Overall, table 3 demonstrates that the executive–analyst communication network exhibits moderate clustering, periodic fragmentation, and eventual consolidation, consistent with structural adaptation during large-scale technological transformation.

Community Structure Visualization

Figure 2 presents representative community structures for early, middle, and late observation periods. The visualizations demonstrate that community clustering is consistently present, with distinct analyst–executive groupings forming in each quarter. In earlier periods, communities appear moderately separated with multiple small clusters. During mid-period observations, the network exhibits tighter clustering around key executives. In later quarters, community structures remain identifiable but appear more centralized around dominant executive nodes. These structural patterns visually confirm the modularity results and indicate that community formation persists across time, albeit with evolving configurations.



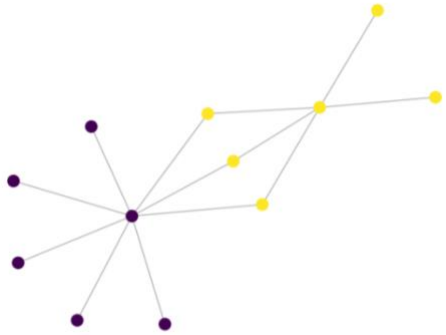


Figure 2 Community Structure Snapshots

The visual evidence confirms that community formation persists throughout the observation period, though its configuration evolves. Early fragmentation gives way to mid-period consolidation and eventual structural centralization in later quarters. These changes visually reinforce the quantitative findings from modularity and density analyses, demonstrating that Meta's strategic transformation toward the metaverse coincides with observable restructuring in corporate communication networks.

Modularity Evolution

Figure 3 illustrates the temporal evolution of modularity scores across quarterly interaction networks. Modularity measures the strength of community division within the network, with higher values indicating stronger clustering and greater structural fragmentation. Across most quarters, modularity remains within the range of 0.22 to 0.32, indicating persistent but moderate segmentation in executive–analyst interaction patterns. This suggests that while communities are consistently formed, the network does not exhibit extreme polarization or isolation among clusters. A pronounced peak is observed in Q4_2019 (0.4017), representing the highest level of structural fragmentation during the study period. This spike indicates a temporary intensification of community separation, where interaction clusters became more internally cohesive yet more distinct from one another. Following 2022, modularity values stabilize within a narrower range, with fewer extreme fluctuations. This stabilization suggests increasing structural consolidation in communication patterns, consistent with the broader trend toward network centralization identified in subsequent analyses.

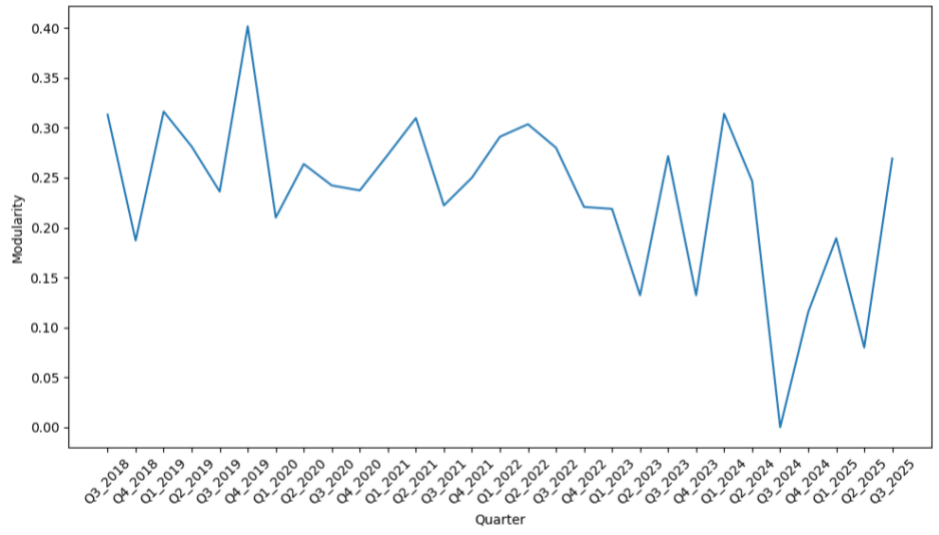


Figure 3 Modularity Evolution Over Time

Community Size Distribution

Figure 4 presents the distribution of community sizes for the final observation period (Q3_2025). The histogram illustrates the number of nodes contained within each detected community. The results indicate that community sizes are unevenly distributed, with one dominant cluster and one or more smaller clusters. This imbalance suggests partial centralization within the interaction network, where a core executive cluster attracts a larger proportion of analyst connections. Such distribution patterns are consistent with moderate modularity values observed in table 3, where clustering exists but does not result in extreme fragmentation. The presence of a dominant community indicates structural consolidation, while smaller communities reflect residual segmentation in interaction patterns. This distribution supports the interpretation that executive communication became increasingly concentrated during later transformation stages.

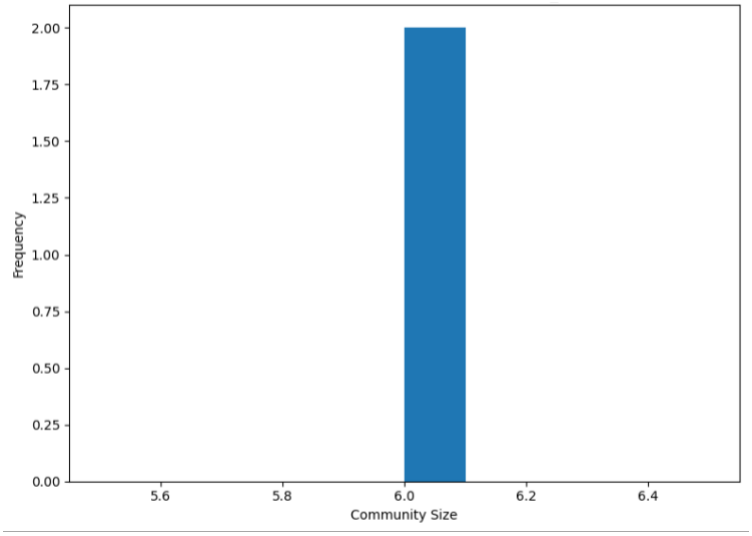


Figure 4 Community Size Distribution

The distribution shows an imbalance in community sizes, with one dominant

cluster and one smaller cluster. This pattern indicates partial centralization of interactions around a core executive group. The presence of a larger community suggests structural consolidation, while the smaller community reflects residual segmentation. Overall, the distribution supports the finding that communication became increasingly concentrated during the later stages of the metaverse transformation.

Network Density Dynamics

Network density measures the proportion of actual connections relative to all possible connections within the network. Higher density values indicate stronger overall connectivity and interaction concentration among nodes. Figure 5 presents the evolution of network density across quarters.

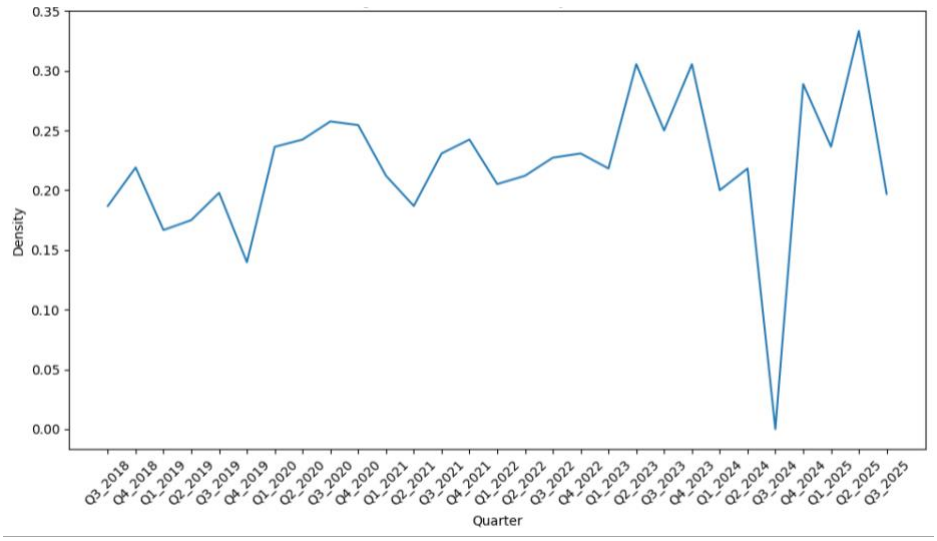


Figure 5 Network Density Evolution

As shown in figure 5, density values exhibit a gradual upward trend after 2020. Earlier periods display relatively lower density levels, while later quarters demonstrate increased interaction concentration. This upward trajectory suggests that executive–analyst communication became progressively more interconnected and centralized during the later stages of Meta's metaverse transformation. The increasing density reflects consolidation of engagement patterns around key executive actors.

Community Stability Analysis

Community stability measures the persistence of community membership across consecutive quarters. Higher stability values indicate that nodes remain within the same communities over time, reflecting structural consistency in interaction patterns. Figure 6 displays the Community Stability Index across the observation period.

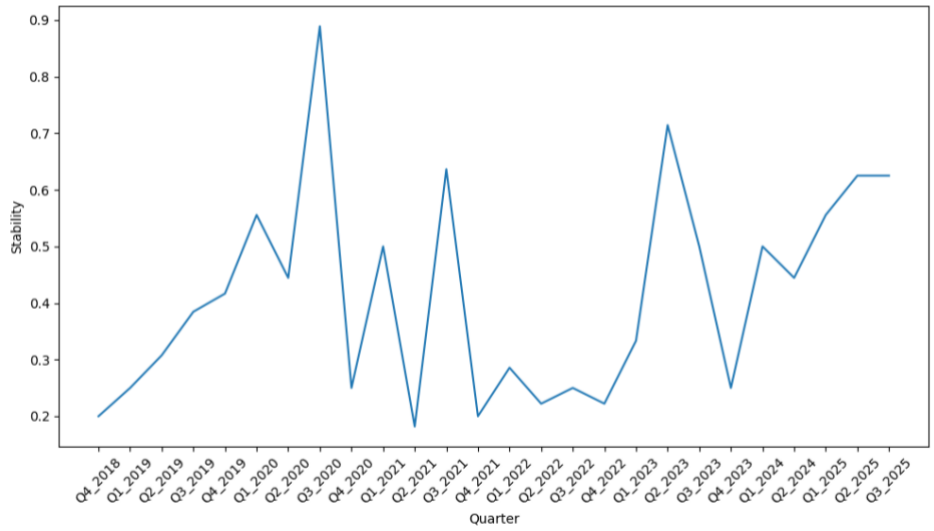


Figure 6 Community Stability Index

As shown in figure 6, stability values range from 0.18 to 0.89, indicating alternating periods of structural reorganization and consolidation. A notable peak occurs around Q3_2020, suggesting strong persistence of community configurations during that interval. In later periods, particularly after 2023, stability values trend upward, reflecting increasing structural consistency. These findings suggest that community configurations fluctuated during earlier transformation phases but gradually stabilized as Meta's strategic direction toward the metaverse became more consolidated.

Leadership Centralization and Influence Dynamics

Leadership centralization is analyzed using degree, betweenness, and eigenvector centrality to capture different dimensions of influence within the interaction network. Degree centrality reflects direct connectivity, betweenness centrality measures brokerage control over communication paths, and eigenvector centrality captures influence based on connections to other influential nodes. Table 4 identifies the most central analyst and executive in each quarter based on degree centrality, representing the actors with the highest number of direct interactions.

Table 4 Top Analyst and Executive per Quarter

Quarter	Top Analyst	Analyst Degree Centrality	Top Executive	Executive Degree Centrality
Q3_2018	Douglas Anmuth	0.1538	David Wehner	0.5385
Q4_2018	Anthony DiClemente	0.2143	David Wehner	0.6429
Q1_2019	Douglas Anmuth	0.1333	David Wehner	0.6000
Q2_2019	Eric Sheridan	0.1333	David Wehner	0.7333
Q3_2019	Douglas Anmuth	0.1538	David Wehner	0.7692
Q4_2019	Brian Nowak	0.1250	Mark Zuckerberg	0.5625
Q1_2020	Brian Nowak	0.2000	David Wehner	0.7000
Q2_2020	Eric Sheridan	0.1818	Mark Zuckerberg	0.5455
Q3_2020	Brian Nowak	0.1818	Mark Zuckerberg	0.7273

Q4_2020	Brian Nowak	0.2000	David Wehner	0.6000
Q1_2021	Brian Nowak	0.1818	David Wehner	0.5455
Q2_2021	Youssef Squali	0.2308	David Wehner	0.6923
Q3_2021	Brian Nowak	0.1667	Dave Wehner	0.8333
Q4_2021	Eric Sheridan	0.2727	Dave Wehner	0.6364
Q1_2022	Brian Nowak	0.1667	David Wehner	0.5833
Q2_2022	Justin Post	0.1818	Dave Wehner	0.6364
Q3_2022	Justin Post	0.2727	David Wehner	0.4545
Q4_2022	Eric Sheridan	0.2500	Susan Li	0.7500
Q1_2023	Brian Nowak	0.2000	Susan Li	0.9000
Q2_2023	Eric Sheridan	0.2500	Mark Zuckerberg	0.7500
Q3_2023	Brian Nowak	0.2500	Susan Li	0.7500
Q4_2023	Eric Sheridan	0.2500	Susan Li	0.7500
Q1_2024	Doug Anmuth	0.2000	Susan Li	0.6000
Q2_2024	Brian Nowak	0.2000	Susan Li	0.7000
Q4_2024	Brian Nowak	0.2222	Mark Zuckerberg	0.7778
Q1_2025	Brian Nowak	0.2000	Susan Li	0.8000
Q2_2025	Eric Sheridan	0.2500	Mark Zuckerberg	0.7500
Q3_2025	Doug Anmuth	0.1818	Mark Zuckerberg	0.7273

The results indicate recurring prominence among several analysts, particularly Brian Nowak and Eric Sheridan, who frequently emerge as the most central analysts across multiple quarters. This consistency suggests stable engagement patterns from key financial actors throughout the observation period. On the executive side, centrality dominance evolves. David Wehner is highly central during earlier quarters, reflecting strong engagement during pre- and early-transition phases. In mid-period observations, Susan Li emerges as a dominant node, indicating a redistribution of communication prominence. In later quarters, Mark Zuckerberg increasingly becomes the most central executive, particularly from 2023 onward. This progression reflects a structural shift in communication emphasis toward the CEO during advanced stages of the metaverse transformation. To further examine influence beyond direct connections, figure 7 presents the temporal evolution of betweenness and eigenvector centrality for key executives.

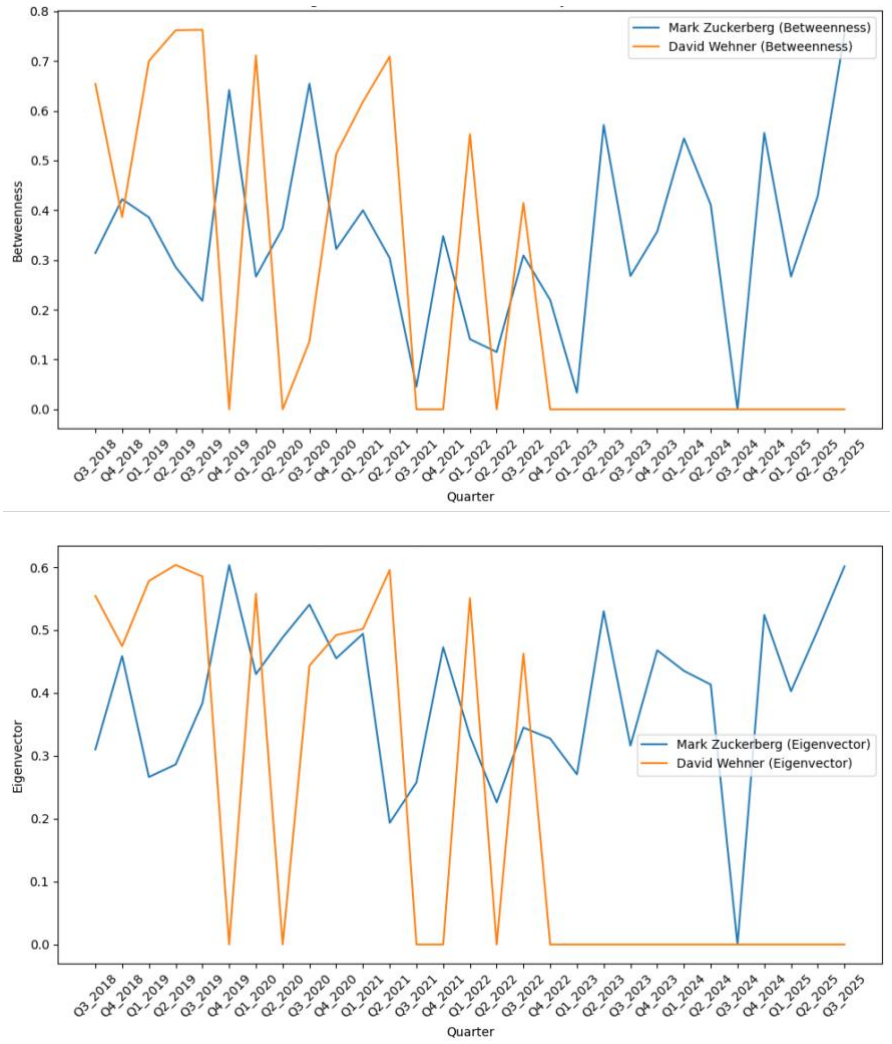


Figure 7 Centrality Evolution

Figure 7 shows that Mark Zuckerberg's betweenness centrality increases notably in later quarters, indicating a growing brokerage role in mediating communication between analysts and other executives. In contrast, David Wehner's betweenness values decline over time, suggesting reduced structural brokerage influence. Figure 7 reveals a similar pattern in eigenvector centrality. In later periods, influence becomes increasingly concentrated around the CEO, indicating that not only does the CEO maintain many direct connections, but these connections are also to structurally important nodes within the network. Collectively, these findings demonstrate a measurable transition from CFO-centered communication dominance to CEO-centered structural centralization. This shift aligns with the strategic reorientation toward the metaverse, where executive-level narrative control and leadership visibility appear increasingly consolidated at the highest organizational level.

Discussion

This study examined how Meta's strategic transition toward the metaverse is reflected in the structural evolution of its corporate communication network. The findings demonstrate that large-scale technological transformation is

accompanied by measurable restructuring in executive–analyst interaction patterns. Community detection results indicate that while clustering persists throughout the observation period, the degree of fragmentation fluctuates across strategic phases. The notable modularity peak in Q4_2019 suggests a period of intensified segmentation prior to full strategic consolidation. In contrast, the stabilization of modularity values after 2022 reflects increasing structural coherence as the metaverse initiative matured.

The gradual increase in network density further supports the interpretation of communication consolidation. Earlier quarters exhibit lower interaction concentration, whereas later periods show higher density levels, indicating stronger connectivity among key actors. This pattern suggests that as strategic uncertainty decreases, communication becomes more centralized and interconnected. Such structural consolidation aligns with organizational network theory, which posits that periods of major strategic transformation often involve increased coordination and alignment around central leadership figures.

Leadership centralization analysis reveals a clear transition in executive dominance. Early stages of the observation period are characterized by strong CFO-centered communication prominence. Over time, influence shifts toward the CEO, as evidenced by rising betweenness and eigenvector centrality values. The increase in betweenness centrality indicates growing brokerage control over communication pathways, while higher eigenvector centrality reflects influence within the broader structural network. This transition suggests that during advanced stages of the metaverse transformation, communicative authority becomes increasingly concentrated at the highest executive level.

The Community Stability Index provides additional insight into structural adaptation. Early fluctuations in stability values indicate periodic reorganization of interaction clusters, consistent with transitional adjustment phases. In later quarters, increasing stability suggests that community configurations become more persistent, reflecting the maturation of strategic direction and clearer governance alignment. Together, these findings illustrate that metaverse transformation is not purely technological but also relational, reshaping interaction hierarchies and leadership structures within corporate governance networks.

From a theoretical standpoint, this study extends metaverse research beyond technological architecture by introducing a relational and structural perspective. The results demonstrate that immersive digital transformation manifests in observable shifts in clustering patterns, network cohesion, and executive centralization. By applying temporal graph modeling and Louvain community detection to corporate communication data, this research contributes to organizational network theory and platform governance literature.

Practically, the findings suggest that monitoring network metrics such as modularity, density, and centrality may provide valuable indicators of governance restructuring during strategic technological pivots. Increasing centralization and consolidation may signal alignment, while fragmentation spikes may reflect transitional uncertainty.

Conclusion

This study investigated the temporal evolution of executive–analyst interaction networks during Meta’s transition toward the metaverse using dynamic social

network analysis and Louvain community detection. The findings reveal persistent but fluctuating community clustering, a gradual increase in network density, periods of structural reorganization followed by stabilization, and a clear shift from CFO-centered to CEO-centered communication dominance. These results provide quantitative evidence that large-scale technological transformation toward the metaverse is accompanied by measurable restructuring in corporate communication networks. Strategic pivots reshape not only technological investment priorities but also relational governance structures and executive influence distribution.

Future research may integrate textual analysis, topic modeling, or multi-layer network approaches to further examine how strategic narrative content interacts with structural communication dynamics. Expanding the analysis across multiple firms undergoing immersive digital transformation would also enhance generalizability. Overall, this study demonstrates that metaverse transformation extends beyond technological innovation, influencing organizational structure, leadership centralization, and communication network configuration within platform-based ecosystems.

Declarations

Author Contributions

Conceptualization: M.J.A. and J.O.G.; Methodology: J.O.G.; Software: M.J.A.; Validation: M.J.A. and J.O.G.; Formal Analysis: M.J.A. and J.O.G.; Investigation: M.J.A.; Resources: J.O.G.; Data Curation: J.O.G.; Writing Original Draft Preparation: M.J.A. and J.O.G.; Writing Review and Editing: J.O.G. and M.J.A.; Visualization: M.J.A.; All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Not applicable.

Informed Consent Statement

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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