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An Integrated BSC–Fuzzy DEMATEL–ANP to Continuous Improvement in Electronic Manufacturing

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Abstract **-** To remain competitive, companies must satisfy customers by improving production processes and tracking progress with KPIs. Continuous Improvement (CI) programs are therefore essential. A review of 10 Scopus-indexed articles from the past five years finds no study integrating Balanced Scorecard (BSC), Fuzzy DEMATEL, and Analytical Network Process (ANP) for CI in manufacturing; most research focuses on the environment, construction, and supply chains. PT. XYZ, as a manufacturing company, has a CI program in place, but it has not been examined in depth. This study addresses that gap by applying an integrated BSC–Fuzzy DEMATEL–ANP approach. The ANP then identifies the most influential factors and prioritizes them, leading to strategic recommendations to strengthen the company's CI initiatives. Based on the Fuzzy DEMATEL analysis, 10 of 19 factors were identified as causal factors and 9 as effect factors. ANP also successfully identified the priority factors. By plotting the (D-R) value and ANP value into a graph, the Top five factors were identified to define the strategies of the CI Program. The strategy focuses on positive (D-R) values, indicating causal factors. The Involvement of the Leadership Team/ Management (ANP: 0.164625) is the most important factor in developing the Continuous Improvement (CI) program. Followed by Return on Investment (ANP:0.130923), Comprehensive CI Training Program (ANP: 0.100193), Percentage of Trained Employees (ANP: 0.049374), and Existence of CI Committee (ANP: 0.042059).

Keywords**:** electronic manufacturing, continuous improvement, balanced scorecard, Fuzzy-DEMATEL, ANP

I. INTRODUCTION

Manufacturing companies currently face many problems, such as unreliable production processes, poor product quality, financial losses, delayed product deliveries, and more. However, companies often do not understand the root causes. Typically, manufacturing problems stem from inadequate workforce qualifications, poor working conditions, outdated technology, material supply issues, and other factors that reduce company efficiency. As a result, this decline can cause customer dissatisfaction and loss of market position.

In the manufacturing industry, the Continuous Improvement (CI) Program is a vital initiative aimed at enhancing efficiency, quality, and productivity on an ongoing basis. It reflects a quality-oriented philosophy grounded in the belief that processes can always be improved and should be continually evaluated and improved. Its significance lies in its contribution to quality enhancement, customer satisfaction, employee engagement, and overall productivity. CI encompasses a series of systematic activities aimed at improving performance. In manufacturing, these activities primarily focus on streamlining production processes, especially by eliminating waste. By fostering flexibility, CI enables the efficient production of diverse products or services, rapid changeovers, responsiveness to fluctuating demand, and improved quality standards. Moreover, it supports agile adaptation to evolving customer requirements, emphasizing mass customization over traditional mass production (Barinua & Sunday, 2022). Approaches such as Lean, Six Sigma, and Total Quality Management have substantially improved organizational performance by reducing inefficiencies and strengthening quality standards. A longitudinal research design would

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allow examination of how sustained application of these methodologies influences both quality-related expenditures and broader operational results (Shukor & Yaakub, 2025).

An analysis of 109 studies indicates that implementing Lean Six Sigma (LSS) has a substantial positive impact on operational performance. Specifically, 77.98% of the reviewed research reported significant reductions in cycle time and defect rates. Financial outcomes, such as cost savings and return on investment (ROI), exhibited moderate to strong effects, with 63.58% of studies documenting cost reductions. Quality improvements were also consistently observed, particularly in First Pass Yield, where 67% of studies reported improved quality metrics (Mavhunga et al., 2024).

In some companies, the CI function is fully integrated into every division of the organization. Many others have established a dedicated CI department, separate from other functions, yet still collaborate daily to implement and complete planned improvement programs. PT. XYZ is one such company that has adopted this strategy.

The company has run its CI program since 2006 (19 years ago). It involves various methods and tools to identify, analyze, and implement improvements across its production processes. The company uses these methods to execute several project categories, such as Advanced Manufacturing Projects, Lean Six Sigma Projects, Operating Leverage Projects, and Supply Chain Deflation Projects. At the beginning of each year, goals are set. All departments collaborated to execute the projects and achieve the site's goals.

Based on the analysis of Key Performance Indicator (KPI) achievement percentages from January to June 2025, as illustrated in Figure 1, the company's average performance reached only about 80% of the 100% KPI target each month. Various factors undoubtedly contribute to this issue; however, the Continuous Improvement (CI) program is considered crucial to achieving KPIs within an organization. This is one of the underlying reasons for conducting this research.

A comprehensive review of 98 scholarly articles conducted by Sahmi & El Abbadi (2024) underscores the strategic significance of Kaizen as a continuous improvement methodology. The findings reveal that Kaizen is not merely a set of incremental improvement practices but a holistic approach that fosters organizational adaptability and resilience. By embedding Kaizen principles into daily operations, organizations can systematically identify inefficiencies, reduce waste, and enhance process reliability. This iterative problem-solving culture promotes sustained performance improvements across multiple dimensions, including quality, cost efficiency, and operational flexibility. Furthermore, Kaizen supports long-term sustainability by engaging employees at all levels, strengthening organizational learning and innovation capabilities. Its emphasis on incremental, continuous change helps firms remain competitive in dynamic market environments while aligning operational practices with strategic objectives.

Various methodological approaches can be applied; in this study, the authors employ a combination of the Balanced Scorecard (BSC), Fuzzy DEMATEL, and the Analytical Network Process (ANP). Kaplan and Norton (2001, as cited in Mio et al. 2022), observed that while the Balanced Scorecard (BSC) was initially introduced as a performance measurement tool, it has progressively evolved into a strategic management framework. This transformation enables organizations to integrate planning and execution while identifying critical value drivers they can leverage to optimize strategic outcomes. Zadeh (1965, as cited in Akyuz & Celik, 2015), stated that fuzzy logic, introduced by Lotfi A. Zadeh in 1965, is a powerful approach to addressing vagueness, ambiguity, and uncertainty in human judgment and decision-making. In real-world practice, decision-making problems often involve imprecision because goals, constraints, and alternative actions are not always known with certainty. Rather than combining various experiences, opinions, ideas, and motivations of individual or group decision-makers, a more effective approach is to convert linguistic terms into fuzzy numbers.

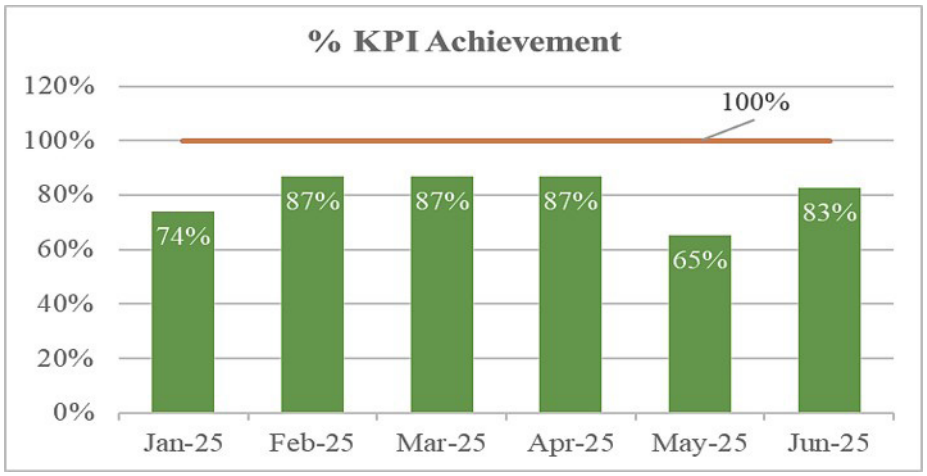


Figure 1 Percentage of KPI Achievement Trend

A review of studies over the past 5 years indicates that these three methods are among the most widely used in organizational performance analysis. The methods are used in several industry types. A literature review of 10 Scopus-indexed articles from the past 5 years that employed the Balanced Scorecard (BSC), DEMATEL, and ANP methods was conducted. No study has used all three methods to analyze Continuous Improvement Programs in electronic manufacturing companies. The supply chain and environment/safety areas dominate the cases, followed by the construction area. Please refer to Table 1 for a detailed breakdown.

Table 1 Distribution of Study Area of Literature Review

Study Area	Qty
Construction	2
Environment/Safety	3
Food Manufacturing	1
Maintenance	1
Natural Disaster	1
Supply Chain	2

Researchers have widely applied integrated methods such as BSC, DEMATEL, and ANP to improve decision-making in complex systems. For example, Lin (2022) showed that combining these approaches helps maritime authorities reduce accidents. Khalilzadeh et al. (2021) used Fuzzy DEMATEL and ANP to identify and prioritize risks in oil and gas projects under uncertainty. Similarly, Osintsev et al. (2021) applied DEMATEL-ANP to design a framework for logistics flows, while Arjomandi et al. (2021) integrated DEMATEL-ANP-VIKOR to select maintenance strategies for safety-critical assets. Kamranfar et al. (2022) combined DEMATEL, Delphi, and ANP to address issues in green construction, and Chukwuma et al. (2023) used IRN-DEMATEL-ANP with geospatial techniques to evaluate groundwater vulnerability. Zaman et al. (2023) employed DEMATEL to assess factors influencing digitalization, warehouse management, and supply chain performance. Overall, DEMATEL provides a structured way to analyze causal relationships and identify key drivers. In one study, grey DEMATEL and expert input from the textile industry were used to validate 23 factors related to digitalization and supply chain effectiveness, highlighting the most critical determinants of operational efficiency.

This study aims to evaluate the factors influencing Continuous Improvement (CI) programs in electronics manufacturing companies through the Balanced Scorecard (BSC) framework, determine the causal relationships and priority rankings among these factors using the integrated Fuzzy DEMATEL and Analytic Network Process (ANP) methods, and formulate strategic directions and priority areas for the development of future CI programs in PT. XYZ and comparable organizations.

II. METHODS

The strategic foundation begins with the Balanced Scorecard (BSC) approach, which was introduced by Kaplan and Norton in the Harvard Business Review (1992, as cited in Kumar et al. 2024), and was originally designed as a strategic performance measurement and management tool that integrates an organization's vision and mission with a mix of economic and non-economic objectives, measurable indicators, and targeted initiatives. By evaluating performance across four key dimensions—financial outcomes, customer satisfaction, internal business processes, and innovation and learning—the framework promotes continuous improvement and value creation. Therefore, since its inception, the BSC has become one of the most extensively researched and widely implemented management tools, evolving from a performance measurement system into a comprehensive strategic management framework that aligns financial and non-financial indicators with long-term organizational objectives.

The Balanced Scorecard has proven effective in embedding sustainability strategies across all organizational levels. Whereas environmental and social initiatives were previously restricted to the Sustainability Department and operated as isolated activities, they have now been elevated to the strategic domain, engaging the entire organization as an integral component of corporate strategy (Suárez-Gargallo & Zaragoza-Sáez, 2023). Next, the Fuzzy DEMATEL method identifies cause-and-effect relationships among criteria. ANP is then used to determine the priority of strategies derived from those relationships.

Based on the 22 factors identified by Formento et al. (2013), these factors were aligned with the Balanced Scorecard perspectives to determine their relevance. Furthermore, we incorporated additional factors pertinent to the company's internal context through discussions with internal experts. We then identified 19 relevant factors. Four factors were financial: Return on Investment (ROI) Guidance (F1), Project Savings (F2), Savings Audit/Validation (F3), and Established CI Savings Rules (F4). From a customer perspective, there are the Number of Customer Complaints (F5) and the Number of Projects Related to Quality and Delivery (F6). From an Internal Business Process perspective, there are seven factors: Workplace wellness and safety (F7), Involvement of Leadership Team/Management (F8), which is consistent with the findings by Galeazzo et al. (2021), who found that the CI–centralization of authority fit shows that centralized control (management involvement) is more effective when continuous improvement is limited, whereas a decentralized, bottom-up approach is preferable when CI is extensively developed. Next are a comprehensive CI program for all Dept./area

(F9), the existence of a CI Committee (F10), an Idea collection system (F11), established CI Audits (5S and Project) (F12), and data and information availability (F13). Finally, from a learning and growth perspective, there are six factors: Comprehensive CI Training Program (F14), which is consistent with Van Assen (2021), who found that, based on a sample of 208 respondents from diverse organizations, training in continuous improvement and the use of a standardized improvement method were positively linked to greater employee involvement. Next are the Involvement of Employees (F15), Percentage of Trained Employees (F16), Percentage of Certified Employees related to LSS (F17), Rewards and Recognition System (F18), and Teamwork (F19).

The number of experts involved in DEMATEL and ANP analysis typically ranges from 3 to 15 experts, as the methods rely on knowledgeable judgments rather than large statistical samples. Three experts were identified to answer the questionnaire. They are professionals in their fields with more than 15 years of manufacturing experience. Expert 1 is a Continuous Improvement Manager, holds a bachelor's degree, is a certified Six Sigma Black Belt (American Society for Quality-ASQ), and has solid experience in process and maintenance engineering. Expert 2 serves as Senior Manufacturing Operations Manager (Head of Department), holds a bachelor's degree, is a certified Six Sigma Black Belt (American Society for Quality-ASQ), has prior CI Manager experience, and is actively involved in the CI Program. Expert 3 serves as Senior Human Resources Manager, holds a master's degree, is human capital certified, and is actively involved in the CI Program.

The process started with developing the questionnaire. The questionnaire was designed and prepared in Microsoft Excel in table format, followed by clear instructions for the experts on how to complete it. The experts' responses were then entered into OnlineOutput.com for further analysis, and the software also produced the results. The authors adopted OnlineOutput for the analysis because of its simplicity, user-friendly interface, data and model editing, no installation required, and, above all, low cost compared with other software tools such as MATLAB, R, and Excel.

Additionally, this analysis used the OnelineOutput software because it can handle many criteria and alternatives without placing a threshold on the number of criteria and alternatives used. Aazagreyir et al. (2022). To process linguistic terms, triangular fuzzy numbers were applied, as presented in Table 2. The primary objective is to determine the cause-and-effect relationship between factors. This approach supports evaluating causal relationships and prioritizing criteria, enabling a more structured, data-driven decision-making process.

The DEMATEL relationship matrix identified relationships between factors. Based on these relationships, a network model was constructed, which served as the basis for the Analytic Network Process (ANP) analysis. Next ANP was applied to determine the priority weights of the identified factors in each BSC perspective. Furthermore, SuperDecisions software (ver. 3.2.0) would also support this analysis. The pairwise comparison matrix was constructed using the crisp values obtained from Matrix T. These values were then compared against one another and mapped to the ANP scale ranging from 1 to 9. This step built on the influence levels derived earlier, enabling more comprehensive prioritization by considering interdependencies and feedback among elements. Through pairwise comparisons and the construction of a supermatrix, ANP synthesized priorities across multiple criteria and clusters, ultimately guiding the selection of the most critical factors in the decision-making process.

The data were collected through questionnaires distributed to three experts at PT. XYZ. The DEMATEL questionnaire was used to compare the 19 factors. The results were then processed using the Fuzzy DEMATEL approach with the assistance of the software onlineoutput.com. The triangular fuzzy number scheme was selected first, as shown in Table 2. Then, the responses of each expert were entered into the software.

III. RESULTS AND DISCUSSION

As shown in Table 3, the horizontal vector (D+R) represents the overall importance of a factor within the system, encompassing both its influence on other factors and the influence exerted on it. This measure provides insight into each factor's relative significance in the network. According to the ranking derived from (D+R), factor F8 (Involvement of Leadership Team/Management) holds the highest level of importance, followed sequentially by F15,

Table 2. The Relationship Between Linguistic Variables and Triangular Fuzzy Numbers

Rating	Linguistic terms	L	M	U
1	No influence	0	0	0.25
2	Very low influence	0	0.25	0.5
3	Low influence	0.25	0.5	0.75
4	High influence	0.5	0.75	1
5	Very high influence	0.75	1	1

F9, F2, F13, F10, F14, F12, F19, F1, F17, F16, F6, F11, F4, F18, F3, F5, and F7. Meanwhile, the vertical vector (D−R) represents the direction and strength of a factor's influence within the system, indicating whether the factor primarily acts as a driving force or is more influenced by other factors in the overall structure. A positive (D−R) value identifies a factor as a causal variable, whereas a negative value designates it as an effect variable. In this study there are 10 factors: F1, F4, F5, F8, F10, F12, F14, F16, F17, and F18 are classified as causal variables. Meanwhile nine factors: F2, F3, F6, F7, F9, F11, F13, F15, and F19 are categorized as effect variables. This classification provides a foundation for understanding the structural dynamics and interdependencies among the factors analyzed.

Figure 2 illustrates the model of significant relationships. This model can be depicted as a diagram in which the (D+R) values are plotted on the horizontal axis and the (D–R) values on the vertical axis. Their coordinates determine each factor's position and interaction at the point (D+R, D–R) within the coordinate system. The QI–QIV determine the priorities of the factors. Q1 is the causal factor and therefore becomes the priority factor for defining the strategy. The opposite (QIII) is the effect factor.

Future strategic planning should prioritize factors classified as causal variables, as they exert significant influence on the overall system. For instance, the Return on Investment (ROI) factor plays a critical role; without clear ROI targets, proposed improvement initiatives lack direction, leading to inefficient project selection and potentially ineffective outcomes. Conversely, effect variables are not primary priorities in strategic planning because they largely depend on causal factors. Therefore, improving causal factors will indirectly enhance effect factors. For example, the Number of Projects related to Quality and Delivery (F6) is strongly influenced by Leadership Team/Management involvement. Consequently, implementing a structured program that actively engages leadership will directly improve the number of quality- and delivery-related projects.

Yazdi et al. (2020) stated that a cause–effect diagram provides significant insights for decision-making. As illustrated in Figure 3, all factors identified within a complex system can be classified into four categories (I, II, III, and IV) based on their position on the influence map. Accordingly, factors located in QI are considered essential because they exhibit high levels of both relation and prominence. In contrast, factors in QIII have low relation and prominence values and are therefore not regarded as primary considerations in strategic planning. By using Matrix - T, the ANP Model was developed (see figure 3).

With reference to the network model above (figure 3), the SuperDecisions software was used to compare the factors. The factors were grouped into clusters according to the Balanced Scorecard (BSC) perspectives. Each factor was interconnected based on the T-Matrix obtained from the Fuzzy DEMATEL analysis. The pairwise comparison scores were

Table 3 Fuzzy DEMATEL Result

Code	Factors	R	D	D+R	D-R
F1	Return on Investment (ROI)	1,481	1,737	3,218	0,256
F2	Project Savings	2,048	1,724	3,772	-0,324
F3	Savings Audit/validation	1,452	1,275	2,727	-0,177
F4	CI Savings rules	1,485	1,581	3,066	0,096
F5	Number of customer complaints	1,158	1,189	2,347	0,031
F6	Number of projects related to quality and delivery	1,573	1,518	3,091	-0,055
F7	Workplace wellness and safety	1,202	1,067	2,269	-0,135
F8	Involvement of Leadership Team/Management	2,053	2,118	4,172	0,065
F9	Comprehensive CI program for all Dept./Area	1,918	1,858	3,777	-0,06
F10	Existence of CI Committee	1,716	1,83	3,546	0,114
F11	Idea collection system	1,597	1,483	3,08	-0,114
F12	Established CI Audit (5S and project)	1,73	1,75	3,479	0,02
F13	Data and information availability	1,92	1,679	3,599	-0,241
F14	Comprehensive CI Training Program	1,611	1,932	3,543	0,321
F15	Involvement of Employees	2,021	1,862	3,883	-0,159
F16	Percentage of Trained Employees	1,359	1,75	3,11	0,391
F17	% of Certified Employees related to LSS	1,591	1,61	3,201	0,019
F18	Rewards and Recognition System	1,492	1,503	2,996	0,011
F19	Teamwork	1,75	1,691	3,441	-0,06

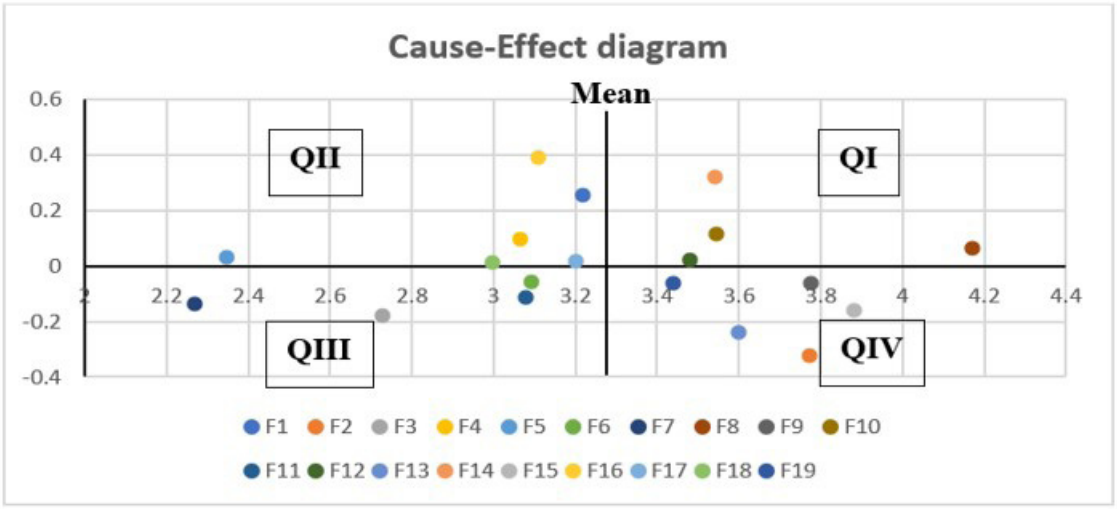


Figure 2 Cause-Effect diagram (Fuzzy Dematel)

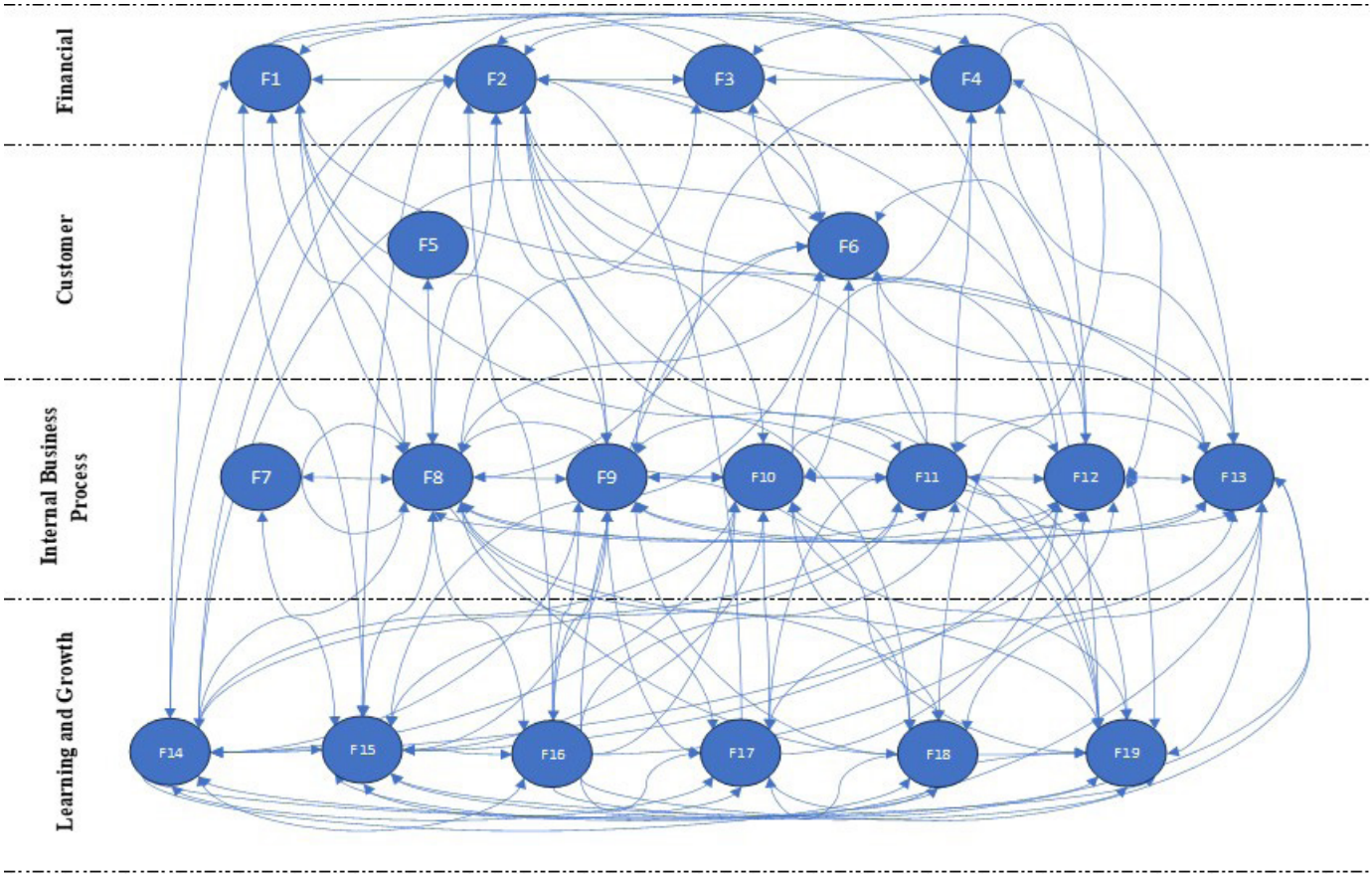


Figure 3 ANP Model of Factors

determined using the (D+R) values as the basis, then rated according to their level of importance, while ensuring the inconsistency value remained below 0.1. Figure 4 presents the model developed using the SuperDecisions software. Table 4 presents the results of the SuperDecisions Software analysis.

Based on the ANP analysis, we identified the prioritized factors for each perspective. By referencing Figure 3, three factors—Return on Investment (ROI), Involvement of the Leadership Team/Management, and Comprehensive CI Training Program—fall within the causal group located in QII and QIV, while one factor—Number of Projects Related to Quality and Delivery—is positioned in QIII. Therefore, when developing future strategic plans, the primary focus should be on the factors in QII and QIV, as these are the most influential elements. Meanwhile, factors situated in QIII, as indicated by the cause–effect diagram, belong to the effect group and thus require only impact monitoring rather than direct intervention.

Based on the results of the above research, the next step is to formulate future strategies using both approaches. The strategies are developed through a graphical method, plotted according to the values of

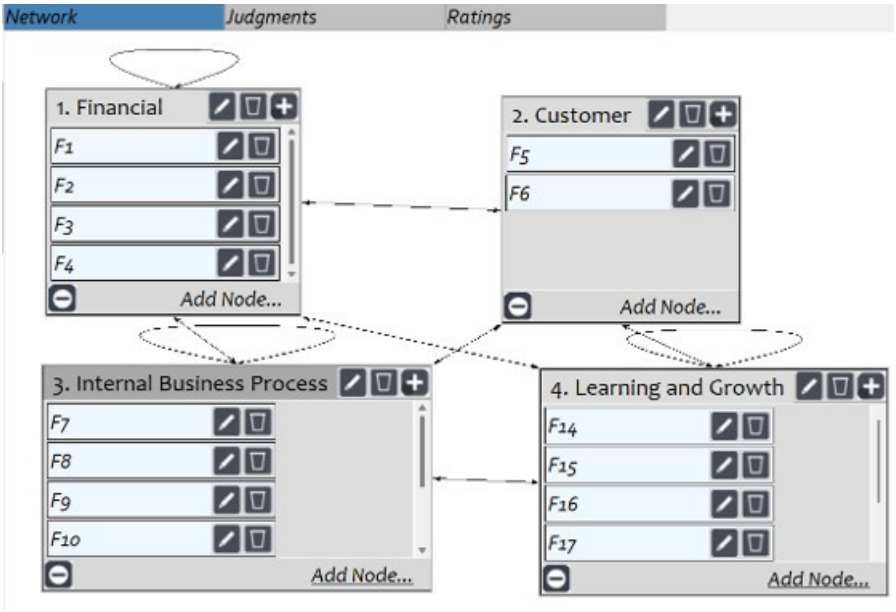


Figure 4 Cluster in SuperDecisions Software

Table 4 Priority factor per each perspective

Perspectives	Code	Factors	Normalized by Cluster	Limiting
Financial	F1	Return on Investment (ROI)	**0.50569**	0.130923
	F2	Project Savings	0.33992	0.088005
	F3	Savings Audit/validation	0.01174	0.003039
	F4	CI Savings rules	0.14266	0.036934
Customer	F5	Number of customer complaints	0.22291	0.027438
	F6	Number of projects related to quality and delivery	**0.77709**	0.095654
Internal Business Process	F7	Workplace wellness and safety	0.02327	0.007527
	F8	Involvement of Leadership Team/Management	**0.50892**	0.164625
	F9	Comprehensive CI program for all Dept./Area	0.18292	0.059172
	F10	Existence of CI Committee	0.13002	0.042059
	F11	Idea collection system	0.01839	0.005985
	F12	Established CI Audit (5S and project)	0.07176	0.023213
	F13	Data and information availability	0.06473	0.020938
Learning and Growth	F14	Comprehensive CI Training Program	**0.33987**	0.100193
	F15	Involvement of Employees	0.32939	0.097051
	F16	Percentage of Trained Employees	0.1676	0.049374
	F17	% of Certified Employees related to LSS	0.05907	0.017937
	F18	Rewards and Recognition System	0.03429	0.010959
	F19	Teamwork	0.06978	0.020552

(D–R) and ANP scores (based on clusters). The (D–R) value is placed on the X-axis, while the ANP score is positioned on the Y-axis. The resulting graph is presented as shown in Figure 5.

The following strategies are recommended based on the five factors with the highest ANP scores and positive (D–R) values: First Priority: Involvement of Leadership Team/Management (F8). Management should demonstrate comprehensive commitment to Continuous Improvement (CI) activities, not only as budget sponsors or stakeholders benefiting from outcomes, but also by actively engaging in every program activity. Second Priority: Return on Investment (ROI) (F1). This factor holds the second-highest priority and also has a positive (D–R) value. Establish clear policies for ROI targets for each project, giving project leaders explicit benchmarks to guide feasibility studies before implementation. Third Priority: Comprehensive CI Training Program (F14). Training programs should reach all levels and

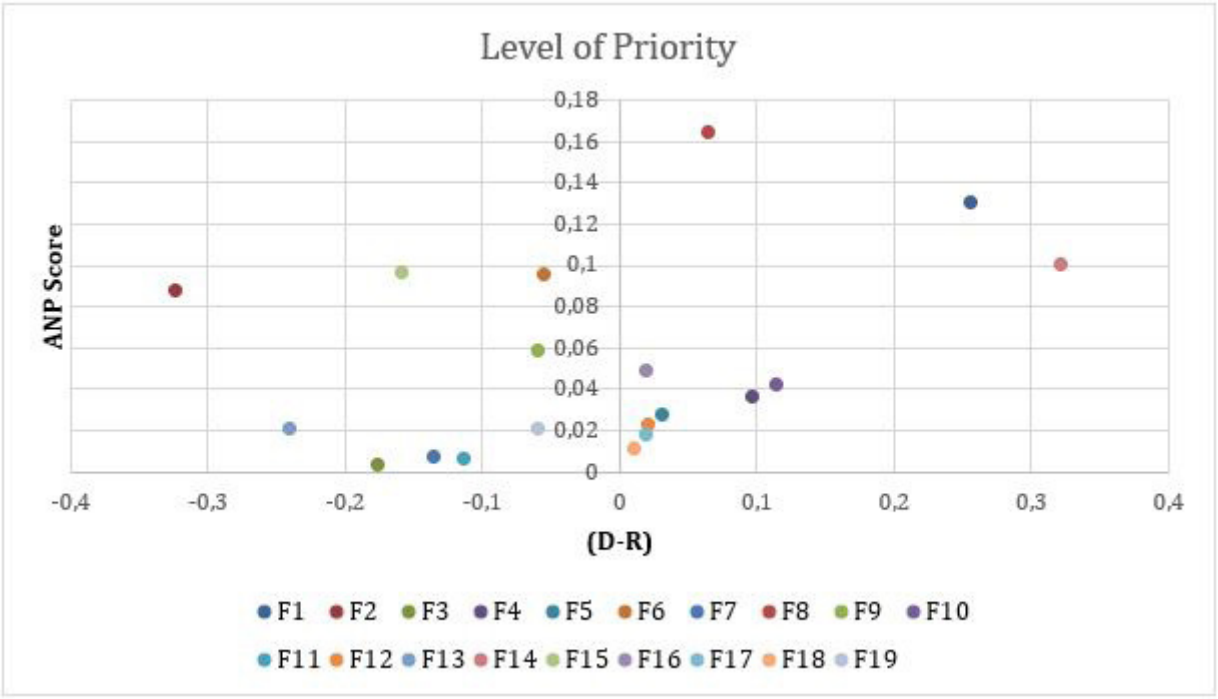


Figure 5 Level of Priority based on the values of (D–R) and ANP scores

functions within the company, equipping employees across departments with the skills needed to implement CI initiatives in their respective areas. Fourth Priority: Percentage of Trained Employees (F16). Place special emphasis on training new employees so they can quickly acquire the competencies needed to contribute effectively to CI efforts. Fifth Priority: Existence of CI Committee (F10). CI Committees serve as extensions of the CI department within each area. Their presence facilitates coordination of CI activities across the organization, supports measurement of program achievements, and helps identify initiatives that can further strengthen CI implementation.

IV. CONCLUSIONS

Based on the findings of this study, the integrated Fuzzy DEMATEL–ANP approach effectively analyzed and identified the most critical factors within each Balanced Scorecard (BSC) perspective in the electronic manufacturing company. The DEMATEL analysis successfully categorized the factors into causal and effect factors. Based on the final ANP results, all factors were ranked from highest to lowest, with the highest values representing the primary priorities. By plotting (D–R) values on the X-axis and ANP scores on the Y-axis, five factors were identified as the most critical due to their high ANP scores and positive (D–R) values. These priority factors are leadership team involvement (F8), return on investment (ROI) (F1), a comprehensive CI training program (F14), the percentage of trained employees (F16), and the existence of a CI committee (F10). Together, these elements form the strategic focus for advancing continuous improvement initiatives. Theoretically, this approach contributed to analyzing and determining the strategy for CI in manufacturing.

However, this research also presents several limitations that should be acknowledged. First, the number of experts participating in the evaluation process was relatively small, which may introduce bias because the professional judgments and experiences of the selected experts inherently shape the analysis. Second, the investigation was conducted within a single electronics manufacturing company. Consequently, the setting's contextual specificity may limit the generalizability of the findings to other industrial sectors or organizational environments. Lastly, the methodological approach employed in this study did not incorporate analytical frameworks capable of generating more granular or comprehensive strategic recommendations.

Therefore, considerable scope for further advancement remains, particularly through applying this approach across a broader spectrum of industries, including but not limited to healthcare, finance, construction, oil-gas, and information technology. Such cross-sectoral implementation would not only test the framework's robustness and generalizability but also reveal industry-specific nuances that could refine its theoretical underpinnings. Moreover, incorporating complementary methodologies such as scenario-based strategic planning would enable the formulation of more sophisticated strategies firmly anchored in the identified key factors. This methodological integration could enhance predictive accuracy, strengthen decision-making, and improve adaptability amid dynamic market conditions and emerging global

challenges. Ultimately, these developments would contribute to a more comprehensive and resilient strategic paradigm, extending both the approach's academic significance and practical utility.

AUTHOR CONTRIBUTIONS

Conceived and designed the analysis, R. D. and C. H.; Collected the data, R. D. and C. H.; Contributed data or analysis tools, R. D. and C. H.; Performed the analysis, R. D. and C. H.; Wrote the paper, R. D. and C. H.

DATA AVAILABILITY

Data openly available in a public repository that issues datasets with DOIs. The data that support the findings of this study are openly available in Zenodo Repository at https://doi.org/10.5281/zenodo.19123625.

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