

Performance Management System for First-Line Chemical Engineers in Indian Process Industries: An Empirical Examination of Attitude and Aptitude Dimensions Towards Establishment of an Integrated Competency Framework

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Abstract: *This study identifies and validates the attitude and aptitude competencies that experienced managers consider critical for the on-the-job performance and managerial development of first-line Chemical Engineers in the Indian chemical process industries. Drawing on survey data from 100 senior managers with experience ranging from 5 to 50 years in managing chemical engineers and process operations in Southern India, the study employs Exploratory Factor Analysis (EFA), Cronbach's Alpha reliability analysis, one-sample t-tests, and the Friedman test to examine 20 competency factors across two dimensions. The attitude dimension yielded three underlying factors- Personal Growth and Engagement, Work Orientation and Discipline, and Leadership and Interpersonal Effectiveness- explaining 74.26% of total variance. The aptitude dimension yielded four factors- Managerial and Operational Capability, Engineering Systems Orientation, Technical Foundation, and Analytical Competence- explaining 78.5% of variance. All attitude factors and eight of ten aptitude factors were rated significantly above the scale midpoint ($p < 0.001$). Grounded in McClelland's (1973) competency theory, Spencer and Spencer's (1993) Iceberg Model, and Becker's (1964) Human Capital Theory, the findings are integrated into a context-specific competency framework suited to the Indian chemical process industry. The study contributes a sector-specific empirical model for developing first-line engineers into effective process industry managers, with implications for talent development, succession planning, and workforce strategy in Indian chemical organisations.*

Keywords: Competency Framework; Chemical Process Industries; Attitude; Aptitude; Exploratory Factor Analysis; Managerial Development; India

1. Introduction

The chemical process industries occupy a distinctive position among manufacturing sectors. Unlike discrete manufacturing environments, chemical and allied process plants operate under conditions of continuous production, tight process coupling, and non-negotiable safety constraints. A deviation that might be recoverable in a batch assembly context can escalate rapidly in a chemical plant- a reality underscored by decades of research linking human factors to process safety incidents (Kletz, 2001; Reason, 1990). In this environment, the quality of the first-line engineer- the individual responsible for translating technical knowledge into daily operational decisions- is not merely an HR consideration. It is a question of organisational reliability.

India's chemical industry has grown substantially over the past decade, with sector analysts and industry bodies projecting continued expansion driven by domestic demand, export growth, and investment in specialty and performance chemicals (IBEF, 2024). Alongside this growth, Indian chemical organisations now operate under intensifying accountability frameworks. The Securities and Exchange Board of India's Business Responsibility and Sustainability Reporting (BRSR) framework, applicable to listed companies, requires disclosures spanning health and safety, workforce management, and environmental stewardship- areas that fall directly within the operational domain of first-

line engineers (SEBI, 2021). Whether first-line engineers possess the attitudinal readiness and technical competency to operate effectively within these accountability demands is a question of both practical and theoretical significance.

A substantial body of research has examined the organisational determinants of employee performance: training and development, leadership quality, reward systems, work environment, and organisational culture (Armstrong, 2014; Robbins and Judge, 2015). These factors create the conditions within which performance is possible, but they do not themselves produce it. As Badawy (1995, p. 54) observed in his foundational work on the transformation of technologists into managers, the primary problems of engineering and R&D management are not technical- they are human. The competencies that determine whether a technically capable engineer becomes an effective first-line leader are predominantly attitudinal and interpersonal.

Despite this recognition, a notable gap persists. Competency framework studies have been conducted predominantly in generic management contexts or service-sector environments, with limited attention to the specific operational demands of process engineering roles (Rao and Palo, 2009). In the Indian chemical process industries specifically, context-specific empirically validated competency frameworks for first-line engineers remain scarce in the peer-reviewed literature. This study addresses that gap.

Drawing on responses from 100 senior managers with experience spanning up to 50 years in managing chemical engineers and process operations across Southern India, this study empirically identifies and validates the attitude and aptitude factors considered critical for first-line engineers' on-the-job performance and managerial development. Using Exploratory Factor Analysis, reliability analysis, and non-parametric ranking tests, the study derives an integrated competency framework grounded in established theory and directly applicable to organisational practice.

The paper is structured as follows. Section 2 reviews the theoretical and empirical literature. Section 3 presents the conceptual framework. Section 4 describes the research methodology. Section 5 reports the statistical findings. Section 6 discusses those findings against the theoretical backdrop. Section 7 presents the integrated competency framework. Section 8 concludes with implications and directions for future research.

2. Review of Literature

2.1 Competency Theory: Foundations

The modern competency movement originates with McClelland's (1973) seminal paper 'Testing for Competence Rather Than for Intelligence', published in the *American Psychologist*. McClelland argued that intelligence and aptitude tests bore little consistent relationship to occupational success, and proposed that the identification of behavioural competencies observable in high performers offered a more valid basis for selection and development. This shifted the field's attention from what people know to what they demonstrably do.

Boyatzis (1982) extended this work through a large-scale empirical study of over 2,000 managers across 41 roles and 12 organisations, defining competency as an underlying characteristic of an employee- including motives, traits, skills, self-image, social role, or knowledge- that results in effective or superior job performance (Boyatzis, 1982, p. 20). His research demonstrated that effective managerial performance depends not on any single attribute but on clusters of competencies spanning cognitive, interpersonal, and self-management domains.

Spencer and Spencer (1993) formalised this multi-level structure through the Iceberg Model, organising competencies along a visibility continuum. Skills and knowledge sit above the surface- observable, measurable, and relatively trainable. Self-concept, traits, and motives lie below- deeper, less visible, harder to develop, and more predictive of sustained superior performance. Surface competencies determine what a person can do; sub-surface competencies determine how consistently and effectively they choose to do it. This distinction provides the theoretical architecture for the present study's separation of aptitude (surface) and attitude (sub-surface) dimensions.

2.2 Human Capital Theory

Becker's (1964) Human Capital Theory provides a complementary economic foundation. Becker argued that

skills, knowledge, and experience constitute a form of capital whose development through education and training yields returns in the form of enhanced productivity. Within this framework, both the technical competencies captured by the aptitude dimension and the behavioural orientations captured by the attitude dimension represent forms of human capital whose systematic development yields organisational value. Becker's distinction between general human capital- transferable across employers- and firm-specific human capital- valuable within a particular organisational context- is especially relevant here, as several aptitude factors identified in this study, including Chemical Engineering Knowledge and SHE Awareness, represent forms of industry-specific human capital whose value is particularly pronounced in chemical process environments (Becker, 1964; Schultz, 1961).

2.3 Attitude, Aptitude, and the Relationship to Performance

The distinction between attitude and aptitude as performance determinants has a long history in organisational behaviour research. Aptitude- encompassing cognitive ability, technical knowledge, and task-specific skills- has been studied as a predictor of performance since the early days of the field. However, as McClelland (1973) demonstrated, aptitude alone is an insufficient predictor of real-world performance, particularly in complex operational and managerial roles.

Attitude, in the organisational behaviour literature, is understood as a multidimensional construct with affective, cognitive, and behavioural components (Robbins and Judge, 2015). An employee's behavioural dispositions- commitment, perseverance, receptivity to feedback, willingness to accept responsibility — are not merely correlates of performance but active determinants of whether technical capability is consistently and effectively deployed. Research consistently demonstrates that task performance is substantially shaped by contextual performance: discretionary, voluntary behaviours that reflect an employee's attitudinal orientation toward work and the organisation (Borman and Motowidlo, 1993; Armstrong, 2014). This distinction between task performance, enabled by aptitude, and contextual performance, enabled by attitude, is central to the present study.

2.4 The Engineer-to-Manager Transition

A distinct body of literature addresses the challenges engineers face when moving from technical to supervisory roles. Badawy (1995) argued that this is among the most demanding career transitions in any professional field, because the skills that produce technical excellence- precision, individual problem-solving, protocol adherence- are frequently in tension with the collaborative and people-centric demands of management. Engineers are typically promoted on the strength of technical ability, with little systematic attention to the behavioural competencies required for effective supervision (Badawy, 1995; Lombard and Crafford, 2003).

Lombard and Crafford (2003) identified a consistent gap between the technical competencies practitioners develop as

engineers and the interpersonal, leadership, and organisational competencies required for managerial effectiveness. In process industries specifically, this gap carries heightened consequences: first-line supervisors bear responsibility for safety compliance, workforce discipline, and the daily translation of operational policy into practice alongside production responsibilities. The structured identification and development of competencies at the first-line level is therefore a strategic necessity, not merely a developmental aspiration.

2.5 Person-Job Fit

Kristof-Brown et al.'s (2005) meta-analysis of 172 studies on Person-Environment fit demonstrated that Person-Job fit- the alignment between an individual's knowledge, skills, and abilities and the demands of the role- consistently predicted performance-related outcomes across diverse occupational contexts. Their findings suggested that fit is most predictive when both surface-level characteristics (technical skills and knowledge) and deeper dispositional characteristics (values and motivations) are considered together. The competency framework developed in this study can be understood, within this theoretical lens, as a specification of the person-side characteristics required for effective fit with the first-line chemical engineer role.

2.6 Contemporary Context: Engineering Competency in Industry 4.0 and Beyond

While the foundational theoretical pillars of this study draw on established scholarship, recent literature reinforces and extends the importance of both technical and behavioural competencies in evolving manufacturing environments. Pinzone et al. (2023), in a structured repository study of Industry 4.0 skill requirements grounded in enterprise reference architecture, confirmed that technical domain knowledge and analytical capability remain essential, but increasingly must be complemented by interpersonal, communication, and adaptability skills- a finding directly convergent with the dual-dimension framework of the present study.

A systematic review by Jabeen et al. (2024), analysing 48 peer-reviewed studies on Industry 4.0's impact on workforce skills in South Asia, identified the shortage of technically grounded yet behaviourally adaptable engineers as a critical constraint on industrial competitiveness in the region. Their finding that technical knowledge in manufacturing is a key barrier to Industry 4.0 adoption in South Asian contexts reinforces the strategic importance of the aptitude factors- particularly Chemical Engineering Knowledge and Analytical Ability- identified in the present study.

Moreira et al. (2025), in a systematic review of engineering competency frameworks in the digital transformation era covering 59 peer-reviewed articles, found that while technical expertise remains essential, soft skills such as leadership, teamwork, communication, and adaptability are increasingly critical for engineering effectiveness. Their seven-dimension competency structure- spanning transversal, social, personal, cognitive, digital, green, and technical skills- offers a contemporary macro-level framework within which the

present study's attitude and aptitude dimensions can be situated: attitude factors correspond broadly to the social, personal, and transversal dimensions, while aptitude factors correspond to the technical, cognitive, and analytical dimensions.

Taken together, this contemporary literature confirms that the integrated approach to attitude and aptitude competency development proposed in the present study is not only theoretically grounded in foundational scholarship but is also aligned with current directions in engineering workforce research. The specific focus on the Indian chemical process sector addresses a contextual gap that these broader studies do not cover.

2.7 Research Gap

The literature establishes three converging theoretical pillars: competency theory (McClelland, 1973; Boyatzis, 1982; Spencer and Spencer, 1993), human capital theory (Becker, 1964; Schultz, 1961), and person-job fit theory (Kristof-Brown et al., 2005). Contemporary research on engineering competency further confirms the dual importance of technical and behavioural dimensions in manufacturing workforce development (Pinzone et al., 2023; Jabeen et al., 2024; Moreira et al., 2025). Existing studies, however, are dominated by Western or broadly South Asian contexts, with no empirically validated attitude-aptitude competency framework documented specifically for first-line chemical engineers in the Indian process industries. This study addresses that gap, contributing a theoretically grounded and contextually specific framework directly applicable to the Indian chemical process sector.

3. Conceptual Framework

The study integrates three theoretical traditions into a unified conceptual framework. Drawing on Spencer and Spencer's (1993) Iceberg Model, competencies are understood as existing on a visibility continuum. The aptitude dimension- engineering knowledge, analytical capability, technical skills- represents the visible, above-surface layer: what an engineer is capable of doing. The attitude dimension- commitment, integrity, perseverance, leadership orientation- represents the sub-surface layer: how consistently and effectively those capabilities are applied in practice.

Within Becker's (1964) human capital framework, both dimensions represent forms of organisational investment with measurable returns. Aptitude competencies correspond to general and industry-specific technical human capital. Attitude competencies correspond to the dispositional human capital that determines whether technical capability is productively applied over time. Neither dimension is sufficient alone: high aptitude without appropriate attitudinal dispositions yields inconsistent performance; high attitude without adequate technical grounding yields effort without effectiveness.

The conceptual model posits that integrated competency- the simultaneous development of both attitude and aptitude dimensions- is the necessary foundation for first-line performance effectiveness and sustained managerial

readiness. Organisational enablers such as training systems, leadership support, and performance management serve as catalysts, consistent with Armstrong's (2014) view that

management systems create the conditions for performance but cannot substitute for individual competence. Figure 1 illustrates the framework.

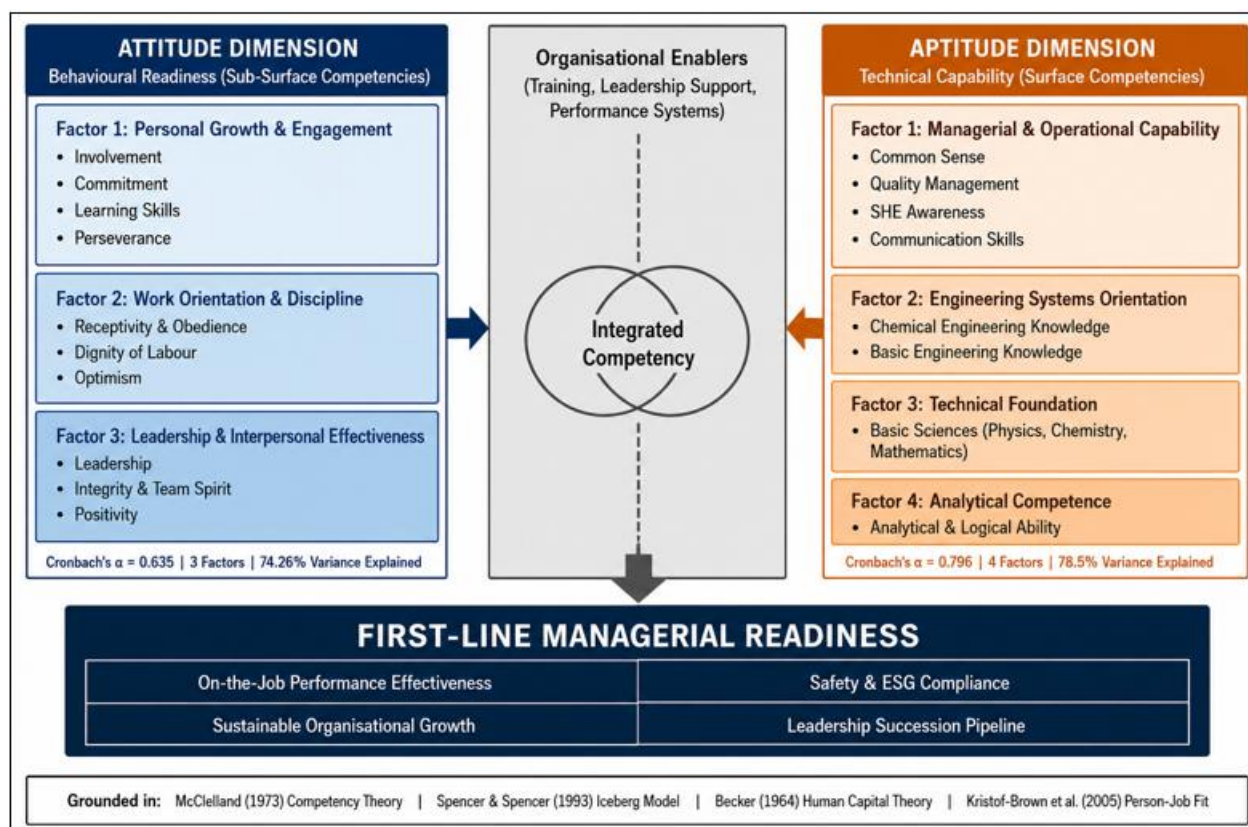


Figure 1: Integrated Competency Framework for First-Line Chemical Engineers in Indian Process Industries (Ramakrishnan, 2025)

4. Research Methodology

4.1 Research Design

This study adopts a descriptive research design to examine how experienced managers perceive and rank the attitude and aptitude factors critical to the development of first-line Chemical Engineers in Indian process industries. A descriptive design is appropriate because the study's objective is to document and analyse existing managerial perceptions systematically, rather than to test causal relationships (Cooper and Schindler, 2014).

4.2 Sample

Primary data were collected from 100 present and retired managers who have managed Chemical Engineers and process operations in chemical and allied industries in Southern India. Respondents' experience ranged from 5 to 50 years. A convenience sampling approach was used, appropriate given the specific professional expertise required of respondents and the practical difficulty of constructing a complete sampling frame for this population. It is important to note that the findings represent experienced managerial perceptions rather than statistically representative industry estimates. While convenience sampling constrains statistical generalisability to the broader population, the collective depth of respondent experience provides substantive content validity for the factors assessed.

Sample adequacy for factor analysis was assessed formally using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity prior to extraction, rather than relying solely on respondent-to-variable ratios, which vary considerably across methodological guidelines (Hair et al., 2014). The obtained KMO values and strong communalities supported factor extraction for both the attitude and aptitude dimensions, as reported in Section 5.

4.3 Instrument

The questionnaire consisted of 20 items: 10 attitude factors and 10 aptitude factors, each measured on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Respondents rated each factor in terms of its perceived importance for the on-the-job performance and managerial development of first-line Chemical Engineers. The attitude factors were: Receptivity and Obedience, Team Spirit and Integrity, Dignity of Labour, Leadership, Learning Skills, Commitment, Perseverance, Optimism, Involvement, and Positivity. The aptitude factors were: Analytical and Logical Reasoning, Common Sense, Communication Skills, Basic Sciences, Chemical Engineering Knowledge, Basic Engineering Knowledge, Quality Management, SHE Awareness, Materials Management, and Costing. The item labelled Common Sense was operationally defined in the instrument as the ability to exercise sound practical judgement in responding to real-time operational situations - a construct aligned with what the literature terms situational

or practical judgement (Sternberg, 2000). Factor identification was informed by an expert consultation process in which approximately 100 industry professionals reviewed and validated the factor list, lending content validity to the instrument design.

4.4 Analytical Methods

Data analysis proceeded in four stages: (i) Cronbach's Alpha for internal consistency; (ii) descriptive statistics and one-sample t-tests against the neutral midpoint of 3; (iii) Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity to assess factor analysis suitability; and (iv) Exploratory Factor Analysis (EFA) using Principal Component Analysis (PCA) with Varimax orthogonal rotation, retaining factors with eigenvalues greater than 1.0 following the Kaiser criterion (Hair et al., 2014). Varimax rotation was selected to maximise the interpretability of the factor structure by minimising the number of variables with high loadings on each factor, producing a cleaner and more theoretically interpretable solution. The Friedman non-parametric test assessed whether significant differences existed in relative importance rankings within each dimension. Percentage analysis was applied to understand the distribution of responses across the scale.

5. Data Analysis and Findings

5.1 Attitude Dimension- Reliability

Cronbach's Alpha for the ten attitude factors was 0.635, indicating moderate internal consistency. This value falls in the 0.60–0.69 range, acceptable for exploratory research (Nunnally, 1978). Critically, given the subsequent emergence of three structurally distinct factors spanning self-management, work orientation, and interpersonal effectiveness, a moderate overall alpha was expected: Leadership and Commitment, for example, are not measuring the same underlying construct, and a high overall alpha would suggest inappropriate item homogeneity for a multi-dimensional scale. The moderate alpha is therefore consistent with- and indeed supportive of- the multi-factor structure confirmed by the EFA.

Table 1: Attitude Dimension- Reliability Analysis

Statistic	Value
Number of Items	10
Cronbach's Alpha	0.635
Interpretation	Moderate- consistent with multi-dimensional construct structure

5.2 Attitude Dimension- Descriptive Statistics and t-Tests

All ten attitude factors were rated significantly above the neutral midpoint of 3 ($p < 0.001$), indicating strong managerial consensus regarding their importance. Involvement ($M = 4.43$) and Commitment ($M = 4.35$) received the highest endorsement. Perseverance ($M = 3.73$), Optimism ($M = 3.72$), and Positivity ($M = 3.72$) received the lowest ratings within the dimension, though all remained significantly above neutral.

Table 2: Attitude Factors- Descriptive Statistics and One-Sample t-Tests (Test Value = 3)

Rank	Factor	Mean	SD	t-value	p-value
1	Involvement	4.43	0.77	18.6	< 0.001
2	Commitment	4.35	0.82	16.44	< 0.001
3	Learning Skills	4.28	0.78	16.42	< 0.001
4	Integrity and Team Spirit	4.13	0.69	16.35	< 0.001
5	Receptivity and Obedience	4.01	0.82	12.28	< 0.001
6	Leadership	3.83	0.82	10.16	< 0.001
7	Dignity of Labour	3.8	0.94	8.49	< 0.001
8	Perseverance	3.73	0.8	9.1	< 0.001
9	Optimism	3.72	0.59	12.26	< 0.001
10	Positivity	3.72	0.82	8.81	< 0.001

5.3 Attitude Dimension- KMO and Bartlett's Test

The overall KMO value of 0.625 indicates that the data are acceptable for factor analysis. Bartlett's Test of Sphericity was highly significant ($\chi^2 = 565.05$, $df = 45$, $p < 0.001$), confirming that the correlation matrix is not an identity matrix and that factor analysis is statistically appropriate. Individual KMO values ranged from 0.424 (Leadership) to 0.864 (Commitment), consistent with a multi-dimensional factor structure.

Table 3: Attitude Dimension- KMO and Bartlett's Test

Variable	KMO
Receptivity and Obedience	0.492
Integrity and Team Spirit	0.68
Dignity of Labour	0.491
Leadership	0.424
Learning Skills	0.733
Commitment	0.864
Perseverance	0.694
Involvement	0.603
Optimism	0.661
Positivity	0.52
Overall KMO	0.625
Bartlett's χ^2 ($df = 45$)	565.05, $p < 0.001$

5.4 Attitude Dimension-Exploratory Factor Analysis

Three factors were retained using the Kaiser criterion (eigenvalue > 1), together explaining 74.26% of total variance- an excellent level for social science EFA (Hair et al., 2014). Extraction used Principal Component Analysis with Varimax rotation. Factor loadings of 0.50 or above are considered meaningful.

Table 4: Attitude Dimension- Eigenvalues and Variance Explained

Factor	Eigenvalue	% Variance Explained
Factor 1	3.297	32.97%
Factor 2	2.228	22.28%
Factor 3	1.901	19.01%
Total (3 Factors)	—	74.26%

Table 5: Attitude Dimension- Factor Loadings

Variable	F1	F2	F3
Learning Skills	0.885	0.025	0.153
Commitment	0.862	0.092	0.021
Involvement	0.925	0.05	0.197
Perseverance	0.701	0.523	0.205
Receptivity and Obedience	0.087	0.824	0.272
Dignity of Labour	0.247	0.818	0.326
Optimism	0.424	0.516	0.452
Integrity and Team Spirit	0.312	0.379	0.703
Leadership	0.083	0.33	0.801
Positivity	0.264	0.275	0.525

Factor 1- Personal Growth and Engagement: Defined by Involvement (0.925), Learning Skills (0.885), Commitment (0.862), and Perseverance (0.701). This factor captures self-directed engagement, ownership of responsibilities, continuous competency development, and persistence through operational challenges.

Factor 2- Work Orientation and Compliance Readiness: Defined by Receptivity and Obedience (0.824), Dignity of Labour (0.818), and Optimism (0.516). This factor reflects openness to instruction and feedback, respect for all categories of operational work, and maintenance of a constructive attitude under conditions of procedural constraint and operational pressure. It represents the behavioural foundation for disciplined, safe working practice.

Factor 3- Leadership and Interpersonal Effectiveness: Defined by Leadership (0.801), Integrity and Team Spirit (0.703), and Positivity (0.525). This factor captures the behavioural attributes associated with managerial effectiveness- influencing others, maintaining ethical conduct, sustaining team orientation, and building constructive working relationships.

5.5 Attitude Dimension- Friedman Test

The Friedman test confirmed that the ten attitude factors are not considered equally important ($\chi^2 = 116.88$, $df = 9$, $p < 0.001$). Managers clearly differentiate among the relative importance of attitudinal competencies, with Involvement, Commitment, and Learning Skills receiving significantly stronger endorsement than Perseverance, Optimism, and Positivity.

5.6 Aptitude Dimension- Reliability

Cronbach's Alpha for the ten aptitude factors was 0.796, indicating good internal consistency- notably stronger than the attitude dimension. This reflects the greater conceptual coherence of technical knowledge and cognitive capability items, which share more variance with one another than do items spanning distinct behavioural domains.

Table 6: Aptitude Dimension- Reliability Analysis

Statistic	Value
Number of Items	10
Cronbach's Alpha	0.796
Interpretation	Good- coherent and reliable aptitude measurement framework

5.7 Aptitude Dimension- Descriptive Statistics and t-Tests

Eight of ten aptitude factors were rated significantly above the neutral midpoint. Materials Management was not significantly different from neutral ($M = 2.92$, $p = 0.278$). Costing was rated significantly below the neutral point ($M = 2.41$, $p < 0.001$), indicating that managers do not view financial costing as a critical aptitude for first-line engineers at this career stage.

Table 7: Aptitude Factors- Descriptive Statistics and One-Sample t-Tests (Test Value = 3)

Rank	Factor	Mean	p-value	Result
1	Common Sense	4.33	< 0.001	Significant
2	Chemical Engineering Knowledge	4.09	< 0.001	Significant
3	Analytical and Logical Ability	4.04	< 0.001	Significant
4	Basic Engineering Knowledge	4.02	< 0.001	Significant
5	Communication Skills	4.01	< 0.001	Significant
6	Basic Sciences	3.62	< 0.001	Significant
7	Quality Management	3.41	< 0.001	Significant
8	SHE Awareness	3.34	0.003	Significant
9	Materials Management	2.92	0.278	Not Significant
10	Costing	2.41	< 0.001	Significantly Below Neutral

5.8 Aptitude Dimension- KMO and Bartlett's Test

The Kaiser-Meyer-Olkin measure of sampling adequacy for the aptitude dimension was [INSERT APTITUDE KMO VALUE FROM SPSS OUTPUT]. Bartlett's Test of Sphericity was highly significant ($\chi^2 = 634.43$, $df = 45$, $p < 0.001$), confirming that the aptitude variables are meaningfully interrelated and factor analysis is statistically appropriate.

Table 8: Aptitude Dimension- KMO and Bartlett's Test

Statistic	Value
Overall KMO (Aptitude)	[INSERT FROM SPSS OUTPUT]
Bartlett Chi-Square	634.43
df	45
p-value	< 0.001

5.9 Aptitude Dimension- Exploratory Factor Analysis

Four factors were retained using the Kaiser criterion, together explaining 78.5% of total variance. Extraction used Principal Component Analysis with Varimax rotation. Two of the four retained factors- Technical Foundation (Basic Sciences) and Analytical Competence (Analytical and Logical Ability)- are each defined by a single variable with a primary loading. While multi-item factors are generally preferred, single-variable factors are methodologically acceptable when three conditions are met: the eigenvalue exceeds 1.0, the communality of the variable is high, and the factor is theoretically distinguishable from adjacent factors (Hair et al., 2014). Both conditions are satisfied here. Basic Sciences represents a distinct knowledge domain - foundational physical and chemical science- that is conceptually separable from applied engineering knowledge (Factor 2) and practical reasoning (Factor 1). Analytical and Logical Ability similarly represents a distinct cognitive capability that does not

conceptually reduce to either engineering domain knowledge or operational judgement. Forcing a three-factor solution would have artificially combined these theoretically distinct constructs, reducing interpretive clarity without methodological justification.

Table 9: Aptitude Dimension- Eigenvalues

Factor	Eigenvalue
Factor 1	3.76
Factor 2	1.71
Factor 3	1.3
Factor 4	1.08
Total Variance (4 Factors)	78.50%

Table 10: Aptitude Dimension- Major Factor Loadings

Variable	Factor	Loading
Common Sense	F1 — Managerial and Operational Capability	0.825
Costing	F1 — Managerial and Operational Capability	0.805
Quality Management	F1 — Managerial and Operational Capability	0.725
SHE Awareness	F1 — Managerial and Operational Capability	0.713
Communication Skills	F1 — Managerial and Operational Capability	0.594
Basic Engineering Knowledge	F2 — Engineering Systems Orientation	0.636
Chemical Engineering Knowledge	F2 — Engineering Systems Orientation	0.543
Basic Sciences	F3 — Technical Foundation	0.85
Analytical and Logical Ability	F4 — Analytical Competence	0.733

Factor 1 (Managerial and Operational Capability) encompasses practical reasoning, communication, quality awareness, safety orientation, and operational judgement-competencies most directly applicable to supervisory responsibilities. Factor 2 (Engineering Systems Orientation) captures core engineering domain knowledge. Factor 3 (Technical Foundation) captures fundamental scientific grounding. Factor 4 (Analytical Competence) captures the logical reasoning capability underlying diagnostic and problem-solving performance.

5.10 Aptitude Dimension- Friedman Test

The Friedman test confirmed significant differences in relative importance ratings across aptitude factors ($\chi^2 = 353.04$, $df = 9$, $p < 0.001$). Managers clearly distinguish among aptitude priorities, placing Common Sense, Chemical Engineering Knowledge, Analytical Ability, Basic Engineering Knowledge, and Communication Skills substantially above Materials Management and Costing.

Table 11: Summary of Statistical Results (***) $p < 0.001$

Statistic	Aptitude Dimension	Aptitude Dimension
Cronbach's Alpha	0.635	0.796
Bartlett's χ^2	565.05*** (df = 45)	634.43*** (df = 45)
Overall KMO	0.625	—
Factors Retained	3	4
Variance Explained	74.26%	78.50%
Friedman χ^2	116.88***	353.04***

6. Discussion

6.1 Attitude Findings in Theoretical Context

The finding that all ten attitude factors were rated significantly above the neutral midpoint is consistent with Spencer and Spencer's (1993) theoretical prediction that sub-surface competencies are broadly critical to sustained effective performance. Managers, drawing on decades of operational experience, endorse this view empirically: not one attitudinal disposition was considered unimportant by the respondent group.

The relative rankings offer contextually specific insights beyond the general literature. The top-ranked factors- Involvement ($M = 4.43$), Commitment ($M = 4.35$), and Learning Skills ($M = 4.28$)- prioritise engagement and self-development over overt leadership traits, with Leadership ranking sixth ($M = 3.83$). This suggests that in the Indian chemical process context, managers weight foundational behavioural engagement above demonstrated leadership capability when assessing first-line readiness. This is consistent with Badawy's (1995) argument that the engineer-to-manager transition requires the prior development of organisational commitment and self-directed learning before leadership orientation can be effectively expressed. The three EFA factors can be read as a developmental sequence in this light: Personal Growth and Engagement is prerequisite to Work Orientation and Compliance Readiness, which in turn enables Leadership and Interpersonal Effectiveness.

6.2 Aptitude Findings in Theoretical Context

Common Sense ranked highest among aptitude factors ($M = 4.33$), a finding that resonates with McClelland's (1973) argument that practical situational judgement is more predictive of operational performance than formal qualification alone. The clustering of Chemical Engineering Knowledge, Analytical Ability, Basic Engineering Knowledge, and Communication Skills in positions two through five reflects the dual demand on first-line engineers: technical competence to understand the process, and communication competence to coordinate teams and report effectively.

The significantly below-neutral rating of Costing ($M = 2.41$) warrants careful interpretation. This finding should not be read as indicating that financial awareness is irrelevant to organisational performance. Rather, it indicates that managers consider cost management a secondary responsibility at the first-line level in the Indian chemical process context- one that becomes more salient at higher managerial levels. This differs from some studies in which financial awareness is included as a core supervisory competency (Rao and Palo, 2009), reinforcing the importance of context-specific competency research rather than the uncritical adoption of generic frameworks. The non-significance of Materials Management ($M = 2.92$) similarly reflects the operational division of responsibilities typical of Indian process plants, where materials procurement tends to reside at plant management or commercial levels rather than at the first-line engineering level.

6.3 The Attitude–Aptitude Complementarity

The overarching finding is that first-line managerial readiness requires both dimensions operating together. Aptitude competencies determine the engineer's capacity for effective performance; attitude competencies determine whether that capacity is reliably exercised over time. An engineer with strong Chemical Engineering Knowledge and Analytical Ability but weak Commitment and Involvement will demonstrate capable performance in isolated instances but fail to sustain it consistently. Conversely, an engineer high on Involvement and Learning Skills but deficient in SHE Awareness or Chemical Engineering Knowledge presents an operational risk regardless of motivational strength. This complementarity is precisely what Spencer and Spencer (1993) predicted from the Iceberg Model: superior sustained performance requires both visible surface competencies and deeper sub-surface dispositions working in concert.

From a human capital perspective (Becker, 1964), this finding has a direct practical implication: organisations that invest in technical training while neglecting attitudinal competency

development- or the reverse- are likely to realise sub-optimal returns on their development expenditure. The integrated framework proposed in Section 7 provides a more complete specification of the human capital profile required for first-line effectiveness in Indian chemical process environments. The practical utility of the framework for safety compliance and workforce accountability- areas increasingly scrutinised under India's evolving corporate reporting requirements- represents a further implication for organisations, though one that requires separate empirical validation beyond the scope of the present study.

7. Integrated Competency Framework

Based on the empirical findings and their theoretical interpretation, this study proposes an Integrated Competency Framework for First-Line Chemical Engineers in Indian Process Industries. The framework, illustrated in Figure 1 above, comprises two primary dimensions- attitude and aptitude- each structured around empirically derived sub-dimensions. Table 12 presents the full structure.

Table 12: Integrated Competency Framework for First-Line Chemical Engineers in Indian Process Industries

Dimension	Sub-Dimension	Key Competencies	Organisational Role
Attitude (Behavioural Readiness)	Personal Growth & Engagement	Involvement, Commitment, Learning Skills, Perseverance	Sustained engagement and self-development orientation
	Work Orientation & Compliance Readiness	Receptivity & Obedience, Dignity of Labour, Optimism	Operational discipline, procedural compliance, and cultural integration
	Leadership & Interpersonal Effectiveness	Leadership, Team Spirit & Integrity, Positivity	People management capability and managerial transition readiness
Aptitude (Technical Capability)	Managerial & Operational Capability	Common Sense, Quality Management, SHE Awareness, Communication Skills	Practical supervisory competence
	Engineering Systems Orientation	Chemical Engineering Knowledge, Basic Engineering Knowledge	Technical domain mastery
	Technical Foundation	Basic Sciences (Physics, Chemistry, Mathematics)	Scientific depth of understanding
	Analytical Competence	Analytical and Logical Ability	Diagnostic and problem-solving effectiveness

The framework rests on four propositions grounded in the theoretical literature and supported by the empirical findings: (a) Attitude and aptitude are both necessary and independently insufficient for sustained first-line performance effectiveness; (b) Within the attitude dimension, Personal Growth and Engagement competencies are foundational to and prerequisite for the expression of Leadership and Interpersonal Effectiveness; (c) Within the aptitude dimension, Common Sense, Chemical Engineering Knowledge, Analytical Ability, Basic Engineering Knowledge, and Communication Skills constitute the core technical threshold for safe and effective first-line performance in a chemical process environment; and (d) An integrated approach to first-line engineer development- one that systematically addresses both dimensions- is more likely to yield sustained performance effectiveness and managerial readiness than development efforts focused on either dimension in isolation.

8. Conclusions and Implications

8.1 Conclusions

This study contributes a context-specific, empirically validated integrated attitude–aptitude competency framework for first-line Chemical Engineers in the Indian process industries. Using data from 100 experienced process industry managers and a multi-method statistical approach, the study confirms that both attitudinal and technical competencies are significantly endorsed by industry practitioners, and that each dimension organises into a coherent and theoretically interpretable factor structure. The three-dimensional attitude framework and four-dimensional aptitude framework, explaining 74.26% and 78.5% of total variance respectively, provide a parsimonious and practically usable specification of first-line competency requirements grounded in the specific operational context of Southern Indian chemical manufacturing.

The study's principal empirical findings are: (a) Involvement, Commitment, and Learning Skills are the most strongly endorsed attitudinal competencies, ranked above Leadership, suggesting that foundational engagement behaviours are

considered more critical than overt leadership traits at the first-line level; (b) Common Sense, Chemical Engineering Knowledge, Analytical Ability, Basic Engineering Knowledge, and Communication Skills constitute the core endorsed aptitude profile; (c) Costing is not considered a critical first-line aptitude in this context; and (d) Both dimensions are jointly necessary for a complete account of first-line managerial readiness.

8.2 Practical Implications

For organisations in the chemical process sector: Selection, appraisal, and development systems should assess both attitude and aptitude dimensions systematically rather than prioritising technical competency alone. Development programmes should identify Involvement, Commitment, and Learning Skills as early-stage indicators of managerial potential, and ensure that Chemical Engineering Knowledge, SHE Awareness, and Analytical Ability are technically grounded before leadership development initiatives are introduced.

For workforce accountability and reporting: The attitudinal competencies of Work Orientation and Compliance Readiness — specifically Receptivity, procedural respect, and operational discipline— have direct relevance to safety management and workforce governance, areas increasingly prominent in India's corporate accountability landscape. Organisations seeking to build credible safety cultures and operationally disciplined workforces may find that systematic investment in these attitudinal competencies yields benefits extending beyond individual performance. However, validating such a connection empirically falls outside the scope of the present study and is recommended as a direction for future research.

For engineering education institutions: The framework provides a structured target for pre-employment and early-career curricula. Institutions training Chemical Engineers for process industry careers should ensure that programmes address not only technical competencies, but also explicitly develop Involvement, Commitment, and Receptivity as programme outcomes — a dimension frequently absent from engineering curriculum design.

8.3 Scope of the Framework

The framework presented in this study should be interpreted as a competency identification framework rather than a predictive performance model. The study identifies competencies perceived by experienced managers to be important for first-line effectiveness, but does not establish causal relationships between individual competencies and subsequent performance outcomes. The empirical basis of the framework is the structured consensus of 100 experienced industry managers, not observed performance data. Longitudinal research establishing direct links between competency profiles and measurable performance outcomes represents an important and necessary next step in developing the predictive utility of the framework.

8.4 Limitations and Future Research

Several limitations qualify the findings. The convenience sampling approach and geographic restriction to Southern India mean that the findings represent experienced managerial perceptions from a specific regional and industry context, rather than statistically representative estimates of the broader Indian chemical industry. Future research should employ probability-based sampling designs across a broader geographic range and larger respondent pools to test the generalisability of the factor structures obtained. The cross-sectional design captures managerial perceptions at a single point in time; longitudinal research tracking whether engineers with stronger attitude–aptitude profiles empirically achieve superior performance outcomes would provide the predictive validity evidence that the present study, by design, cannot supply. Comparative studies across chemical sub-sectors— petrochemicals, pharmaceuticals, specialty chemicals, and agrochemicals — may also reveal sector-specific variations in competency priorities not visible in the present cross-sector sample. Finally, expanding the respondent base to include the first-line engineers themselves, alongside their managers, would allow an investigation of convergence and divergence in competency perceptions across organisational levels.

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