Refinement and Evaluation of Maturity Framework for Assessing Lean Adoption on Indian Construction Sites

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis entitled "**Refinement and Evaluation of Maturity Framework for Assessing Lean Adoption on Indian Construction Sites**" submitted by Devansh Shah (CE23M012) to the Indian Institute of Technology, Madras for the award of the degree of MASTER OF TECHNOLOGY (M.Tech) in Building Technology and Construction Management, is a bonafide record of research work carried out by him under my supervision. The contents of this thesis, in whole or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

India’s construction sector is expanding at an unprecedented pace, yet cost overruns, schedule delays and fragmented workflows remain common; Lean Construction offers a proven path to close these gaps by eliminating waste and creating reliable flow. Sustained adoption of lean construction principles requires structured evaluation and commitment to continuous improvement. Maturity models offer a systematic approach to evaluate current practices, identify gaps and guide organizations towards improving adoption.

This study presents the development and application of an assessment tool for the Lean Maturity Model, developed with extensive input from the Indian construction industry, to assess implementation of Lean practices on projects and identify areas for improvement. The tool evaluates projects on five key dimensions - top management support, process, people & partners, methods & tools, and technology. The dimensions are mapped into four levels of maturity, each further categorised into three sub-levels reflecting specific aspects of each dimension.

Building on this maturity model, an assessment tool was developed with a concise question set mapped to respective dimensions, a transparent five-point Likert scale, an interval-based weighting scheme, and interactive dashboards that display the results in real time. Together, these features turn the maturity model from a static framework into a practical decision-support system, enabling project teams to pinpoint their current level, compare roles, and prioritise improvement actions with confidence.

The maturity model was used to assess lean adoption on four construction projects. Using structured data from project team members and in-person interviews, the maturity level of the projects was assessed and the specific areas that need improvement were identified. The areas common to all projects were gaps in collaboration across vendors, limited leadership involvement, and insufficient training. Based on the assessment it was found that evaluating projects using the maturity model assessment tool results in actionable insights and serves as an effective way for benchmarking, continuous improvement, and sustained lean adoption.

Key Words:

Lean Construction; Maturity Model; Continuous Improvement; Benchmarking; Lean Adoption

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Chapter 1 Introduction

1.1 Background and Overview

India is embarking on the largest build-out of infrastructure in its history. Flagship programmes such as the National Infrastructure Pipeline (₹ 111 lakh-crore, 2020–25) and the Smart-Cities Mission have generated thousands of projects spanning metros, highways, renewable-energy parks, data-centre campuses and cold-chain warehouses (Press Information Bureau, 2020). These initiatives respond to rapid urbanisation—nearly 600 million people are projected to live in Indian cities by 2036—and to the Government's ambition to raise logistics efficiency and industrial competitiveness.

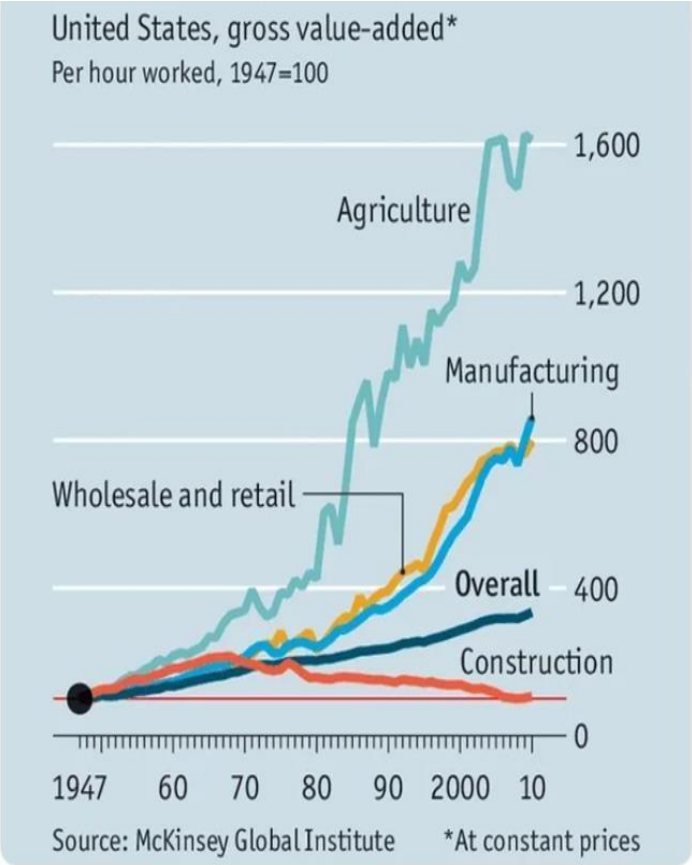

Figure 1 Long-run divergence of labour productivity across economic sectors

Yet delivery capability has not kept pace with this investment ambition. Long-run global data of Figure 1 shows that labour productivity in construction has stagnated, while sectors such as agriculture and manufacturing have multiplied their output per hour. A similar pattern is visible domestically in the Ministry of Statistics & Programme Implementation consistently reports that delayed public projects seldom fall below 30 percent, and cost overruns have remained

between 8 percent and 20 percent for more than a decade as shown in Figure 2. (Ministry of Statistics & Programme Implementation [MoSPI], 2001–2016).

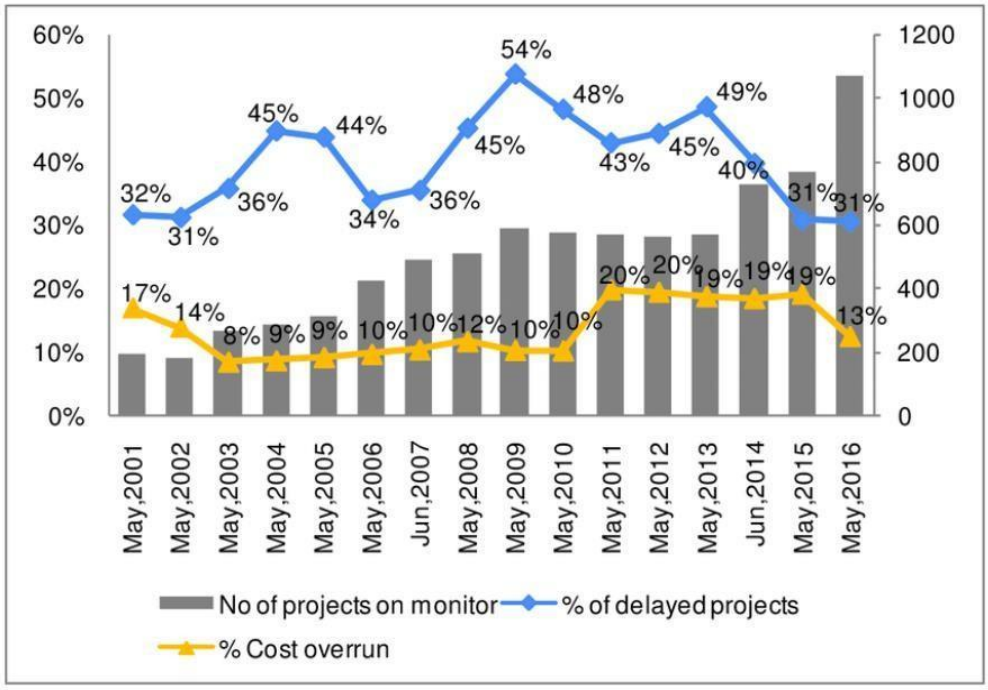

Figure 2 Trend of project delays and cost overruns in Indian public works, 2001-2016

Compounding the challenge, India's construction demand is diversifying as seen in Figure 3. Smart-city retrofits require integrated transport and utility corridors; industrial-corridor projects depend on just-in-time delivery of precast systems; data-centre shells impose tight tolerances and compressed schedules; and cold-storage or Grade-A warehousing complexes seek rapid replication across multiple sites. These varied requirements heighten the need for predictable, high-velocity project execution.

Figure 3 Key growth drivers shaping India's construction demand

International evidence identifies Lean Construction as an effective philosophy for bridging the performance gap. Lean focuses on maximising customer value, creating continuous workflow, applying pull-based planning, and eliminating non-value-adding activities. Meta-analyses report 10–30 percent reductions in schedule and cost, along with improvements in safety and workforce engagement (Ballard & Tommelein, 2021). In India, however, Lean adoption is still sporadic—typically confined to stand-alone initiatives such as 5S campaigns or isolated Last Planner System workshops. Converting these "islands of excellence" into sector-wide routine practice is therefore a pressing need.

1.2 Need for Study

Big improvement programmes succeed when the people involved know exactly where they stand and what the next sensible step looks like. A **maturity model** gives that clarity. The model groups good practices into a small set of levels that run from a basic, ad-hoc stage to one where work is well-organised and continually improved. Each level has short descriptions of what you should see on a site—things like how leaders talk about waste, how crews plan their work, or how problems are recorded and solved.

When a project team answers the model's short questionnaire, they receive a scorecard that shows their present level and the main gaps that stop them from moving up. A follow-up check after six or twelve months tells them if their action plan is working. In this way, the model turns the broad idea of "doing Lean" into a clear, step-by-step journey that everyone can understand. Lean Construction covers many parts of project life: leadership, planning processes, people skills, on-site methods and supporting technology. If one part is ignored—for example, technology is bought but people are not trained—results fade quickly. A maturity model keeps all parts in view and makes sure progress is balanced.

Tools built in other countries often assume constant internet, digital records and crews who already know Lean terms. Many Indian projects work with paper logs, patchy connectivity and workers who speak several languages. They need a tool that is short, can run offline and uses plain words that fit local practice. The **Indian Lean Maturity Model (ILMM)** proposed in this thesis is designed to meet those needs and to help Lean move from scattered trials to daily habit.

1.3 Problem Statement

Indian construction firms and public owners agree that Lean philosophy can reduce delays and cost, but they do not have an easy and trustworthy way to measure how "Lean" their projects really are. The popular tools from abroad feel long, use unfamiliar jargon or expect records that most Indian sites do not keep. Without a simple, home-grown tool managers cannot see their true starting point, compare themselves with similar projects, or choose improvement actions that will give the best return. This research focuses on that missing link.

1.4 Research Questions

The study revolves around three main research questions which form the basis of the thesis progress.

1. **RQ 1 – Limitations Audit**

   What specific shortcomings make existing Lean-maturity models difficult to use or inaccurate on Indian construction projects?

2. **RQ 2 – Tool Design**

   How can a concise, context-sensitive maturity instrument—covering dimensions, weighting and scoring logic—be created for Indian site conditions while remaining methodologically sound?

3. **RQ 3 – Improvement Utility**

   Does feedback from the proposed ILMM help project teams select actions that lead to measurable gains in schedule, cost or quality performance?

1.5 Objectives and Scope

Objective 1 – Identify key drawbacks in the existing Lean Maturity Models with respect to the Indian Construction Industry

A comprehensive review of existing Lean Maturity Models will be conducted to identify limitations and areas where they may not adequately address the specific characteristics and challenges of the Indian construction industry. This objective aims to ensure that the developed ILMM is relevant and applicable to the Indian context.

Objective 2 – Develop a robust tool for Indian Lean Maturity Model (ILMM).

Based on the findings from the previous objective, a robust and comprehensive assessment tool for the ILMM will be developed. This tool will incorporate relevant dimensions, sub-categories, and assessment questions that accurately measure the maturity of Lean implementation in Indian construction organizations.

Objective 3 – Validate on Live Projects

The developed ILMM assessment tool will be implemented on selected Indian construction sites to gather empirical data and validate its effectiveness. This objective aims to ensure that the tool is practical, reliable, and capable of providing meaningful insights to Indian construction organizations for moving up to higher levels of Lean maturity and reaping benefits in terms of time, cost, quality and better safety in all the projects.

Scope

The work looks specifically to projects built and being delivered in India. The pilot case studies serve as a template for other assessments. The scope is to identify best practices and provide organizations with guided steps to mature their Lean practices and achieve better project governance on their projects.

1.6 Chapter Summary

This chapter set the scene for the thesis. It showed that India's construction drive is growing fast but still faces low productivity and frequent overruns. Lean Construction can help, yet present tools to measure Lean progress do not fit local realities. The chapter explained why a maturity model is the right way to give teams a clear, staged path forward and introduced the plan to build an Indian-specific version. It closed with one main research question, three sub-questions and three focused objectives that will guide the rest of the study.

Chapter 2 Literature Review

This chapter synthesises prior scholarship on (a) generic maturity-model theory, (b) project-management models applied in construction, (c) Lean-specific maturity frameworks, and (d) techniques scholars use to weight maturity-model questions. Section 2.1 details the PRISMA-based search strategy; Section 2.2 abstracts generic concepts; Section 2.3 reviews project-management models; Section 2.4 focuses on Lean-specific tools; Section 2.5 compares weighting methods; and Section 2.6 recaps key gaps.

2.1 Systematic Selection of Papers (PRISMA Method)

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), four stages—Identification, Screening, Eligibility and Inclusion—were executed to build a reproducible evidence base. Searches were run on 10 April 2024 in Scopus and ScienceDirect because these databases index the majority of peer-reviewed engineering, management and social-science titles (Lasrado et al., 2021). The exact Boolean string combined three concept blocks:

("lean construction" OR "lean project delivery") AND ("maturity model")

Filters were applied to restrict results to English-language journal articles or conference papers published between 2005 and 2024. Initial hits numbered 23 in Scopus and 21 in ScienceDirect. No duplicate records were found between the two databases, so the post-filter count stood at 38. A title-and-abstract screen removed thirteen papers that lacked a clear connection to both construction and maturity modelling. Full-text reading then excluded four additional papers. Three of those examined maturity in manufacturing or service settings with only passing reference to construction, and one used a maturity concept in an informal, purely narrative way that offered no method or validation. The final evidence base therefore consists of 21 studies. Figure 4 shows the PRISMA flow diagram with the numbers reported above.

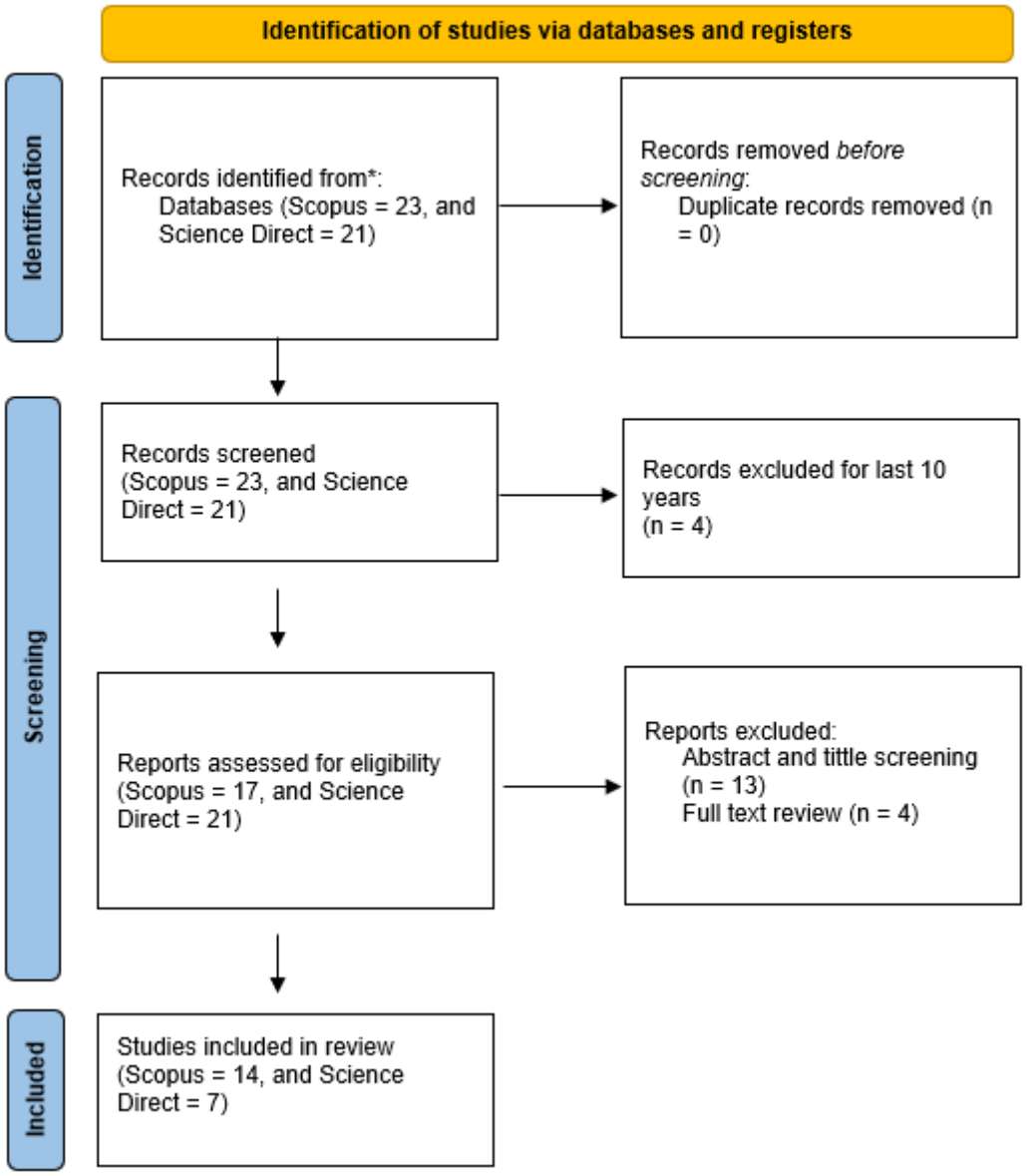

Figure 4 PRISMA Flow diagram

2.2 Maturity-Model Concepts in the General Literature

Researchers in software engineering, information systems, healthcare, logistics and public administration have produced an impressive variety of maturity models. A recent information-systems review counted more than two hundred named frameworks and noted that the rate of new-model publication is still rising (Lasrado et al., 2021). Despite this numerical diversity, four conceptual pillars recur so frequently that they can be treated as defining traits of the genre (Andersen & Jessen, 2003):

- **Progressive levels.** Nearly every model divides capability into discrete stages—usually four, five or six—that trace a path from an initial state of ad-hoc practice to an end state of continuous improvement or optimisation. The famous Capability Maturity Model

Integration (CMMI) uses five stages; OPM3, P3M3 and many Lean models adopt the same number.

- **Observable practices.** Stage descriptions contain behaviours or artefacts that auditors can actually witness: standard operating procedures pinned on a wall, weekly look-ahead plans posted in a control room, or real-time dashboards that track takt-time. This tangibility turns an abstract idea such as *"good collaboration"* into an audit-ready checklist item.
- **Road-mapping.** Because stages are progressive, they function as a map. A team that finds itself at Level 2 does not need to imagine Level 5 in one leap; it can focus on the concrete attributes of Level 3.
- **Benchmarking.** When many organisations use the same model, the resulting scores allow peer comparison. That comparison, in turn, can motivate improvement and justify resource allocation.

2.2.1 Typical Structure

Most authors implement these ideas through a three-layer nesting of dimensions, sub-categories and assessment items (Becker et al., 2009). The outer layer groups items under broad capability areas such as leadership, process, people or technology. Each dimension is divided into sub-categories that narrow the focus—for example, *visual control* is a sub-category of the methods dimension. Finally, each sub-category is anchored by yes/no or scaled questions. Figure 5 (Becker et al., 2009) represents the visual diagram of this hierarchy.

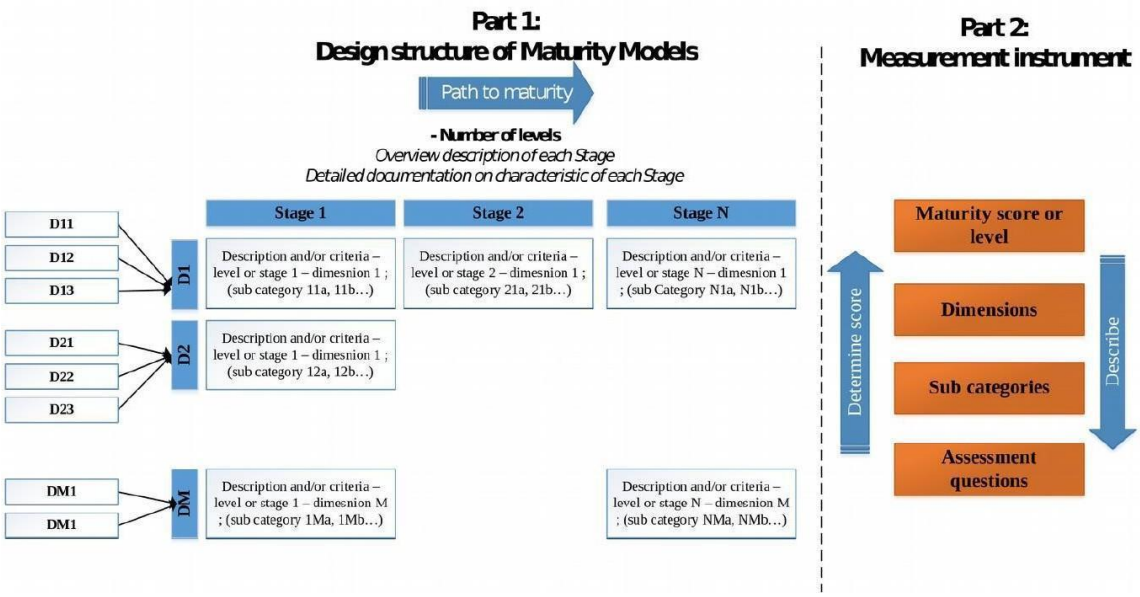

Figure 5 Maturity Model Basic Structure

2.2.2 Benefits and Limits

Using a maturity model gives four practical benefits. First, it turns hidden work habits into visible facts. When staff answer the survey, they must describe what they really do, not what they hope to do. Second, once the gaps are visible, managers can point training and money at the places that need help most. Third, the model supplies a shared set of words. Engineers, supervisors and executives can talk about “Level 2 pull planning” or “Level 3 visual control” and know they mean the same thing. Fourth, repeating the survey later shows in numbers whether last quarter’s action plan worked (Garza-Reyes, 2015).

The literature also warns about two common problems. A model written for one industry or one country may not fit a different setting. This mismatch is called context drift and often shows up as strange jargon or evidence that a site cannot supply. Very long questionnaires create another problem: busy people rush through them, tick boxes without thinking and weaken the data. Researchers call this survey fatigue (Jick, 1979).

2.3 Maturity Models in Construction

Project-management maturity models originated in the defence and software sectors, where complex products evolve under tight configuration control (Brookes & Clark, 2009). Those sectors rely on stable teams, indoor production and extensive digital records. By contrast, building and infrastructure work highlights three persistent complications. First, project teams are temporary: after hand-over, they dissolve. Second, production is outdoor and therefore exposed to weather. Third, multiple employers share the same site under an overarching general-contractor umbrella, which complicates data capture. These differences explain why a maturity model that works smoothly inside an office may struggle on a construction site.

2.3.1 Project-Management-Centred Models

The Organisational Project Management Maturity Model (OPM3), promoted by the Project Management Institute, aligns project outputs with corporate strategy through a catalogue of 151 best practices. Large engineering-procurement-construction (EPC) firms have adopted OPM3 because they possess the document archives needed to prove compliance. Smaller contractors frequently report high audit costs and limited perceived payoff (Project Management Institute, 2013). The P3M3 framework, developed by the UK Office of Government Commerce, distinguishes portfolio, programme and project layers, then rates seven “perspectives” within each layer. Government clients appreciate the breadth, but trade-specific behaviours—such as concrete pour-cycle reliability—remain outside scope

(UK OGC, 2006). The CMMI-Dev model, widely used in design consultancies for defect prevention, carries information-technology language such as configuration items into engineering; site managers have difficulty interpreting those phrases and often skip the software-centric sections (CMMI Institute, 2018). All the three models are summarized in the Table 1 comparing there utilization in Construction industry.

Model	Core Focus	Use in Construction	Main Drawback
OPM3 (PMI)	Align projects with company strategy	Big EPC firms use it for portfolio checks	Needs a lot of paperwork which makes audits costly
P3M3 (UK-OGC)	Rates portfolio, programme, project levels	Adopted by UK public megaprojects	Wording is generic and misses trade-level detail
CMMI-Dev (SEI)	Talks about process quality and defect control	Used by design consultancies	Many software terms which causes site teams to skip parts

Table 1 Project Management Maturity Models

2.3.2 Construction-Specific Models

Recognising these gaps, researchers have created construction-tailored maturity grids. The **MMGP Prado** model in Brazil appends earned-value metrics to a questionnaire, letting contractors anchor maturity stages to familiar schedule and cost baselines. Validation on more than two hundred Brazilian projects confirms the model's diagnostic power for time-cost control (Machado et al., 2021). The **PMMM-C** adapts OPM3 items to the terminology of the Indian PMBoK, thus lowering the linguistic barrier for engineers trained in local professional courses. Empirical evidence remains thin, however, because the model has seen limited deployment (Machado et al., 2021). Finally, the **BIM Maturity Matrix** popular in the United Kingdom and Singapore reframes capability as digital-model use rather than managerial procedure. While the matrix captures the state of 3D and 4D modelling across disciplines, it does not evaluate work-flow stability or waste elimination (UK OGC, 2006).

Model	Focus	Validation Work	Strong Point	Weak Point
MMGP Prado	Time-cost view	200+ Brazilian projects	Uses earned-value data that contractors know well	Scores fixed to Brazilian norms
PMMM-C	Indian PMBOK terms	Few cases run	Local words help understanding	Little test data
BIM Maturity Matrix	Digital-model use	UK and Singapore mandates	Clear BIM roadmap	Ignores work-flow balance

Table 2 Construction Specific Maturity Models

Across the reviewed papers, one pattern is clear: project-management-centred models excel at measuring governance—scope, risk, budget approvals—yet rarely assess production-system maturity. Pull-planning reliability, takt-time balance and crew engagement are almost invisible in these schemes. That gap sets the stage for Lean-specific maturity models.

2.4 Lean-Specific Maturity Models

Lean-Construction maturity models (LC-MMs) add production-system concepts to the project-management baseline. They typically expand dimensions to include pull planning, flow efficiency, visual control and learning culture.

2.4.1 Brief on Lean Models

Acronym & Origin	Levels	Format	Validation status
LESAT – MIT (2007)	3	Qualitative self-audit	Aerospace firms and later trials in hospitals
HELMA – Highways England (2011)	5	Bottom-up metrics & interview guide	Applied to >100 road contracts
LCMM – Claus Nesensohn (2014)	5	55 indicators, Likert scale	Piloted on 12 European projects
LCI-MA – LCI-US (2018)	4	Online survey; spider graph	Used by >80 member companies
LCMR – IIT-Madras (2020)	3	Quantitative; 27 questions	Tested on 8 Indian sites

Table 3 Lean Models

- **LESAT (MIT).** Originally an aerospace assessment tool, later trialled in hospitals. Uses about eighty narrative prompts that ask for qualitative description of practices (MIT LAI, 2007).
- **HELMA (Highways England Lean Maturity Assessment).** Combines thirty quantitative KPIs—such as waste removal rate or accident frequency—with a guided semi-structured interview. Scores populate a radar chart that managers use to compare projects (Highways England, 2017). Figure 6 illustrates a HELMA radar chart with ten Lean topic areas and a five-level capability ring. Such visuals help teams see imbalances immediately.
- **LCMM (Lean Construction Maturity Model).** Developed by Nesensohn for European firms. Contains fifty-five Likert-scale indicators grouped into people, process and culture (Nesensohn et al., 2014).
- **LCI-MA (Lean Construction Institute, U.S.).** Offers a short online survey and returns results as a spider diagram. Used mainly by member companies as a self-diagnostic (Lean Construction Institute, 2018).
- **LCMR (Lean Construction Maturity Rating).** Built at IIT-Madras. Uses twenty-seven closed questions scored in Excel for offline convenience on Indian sites (IIT-Madras, 2020).

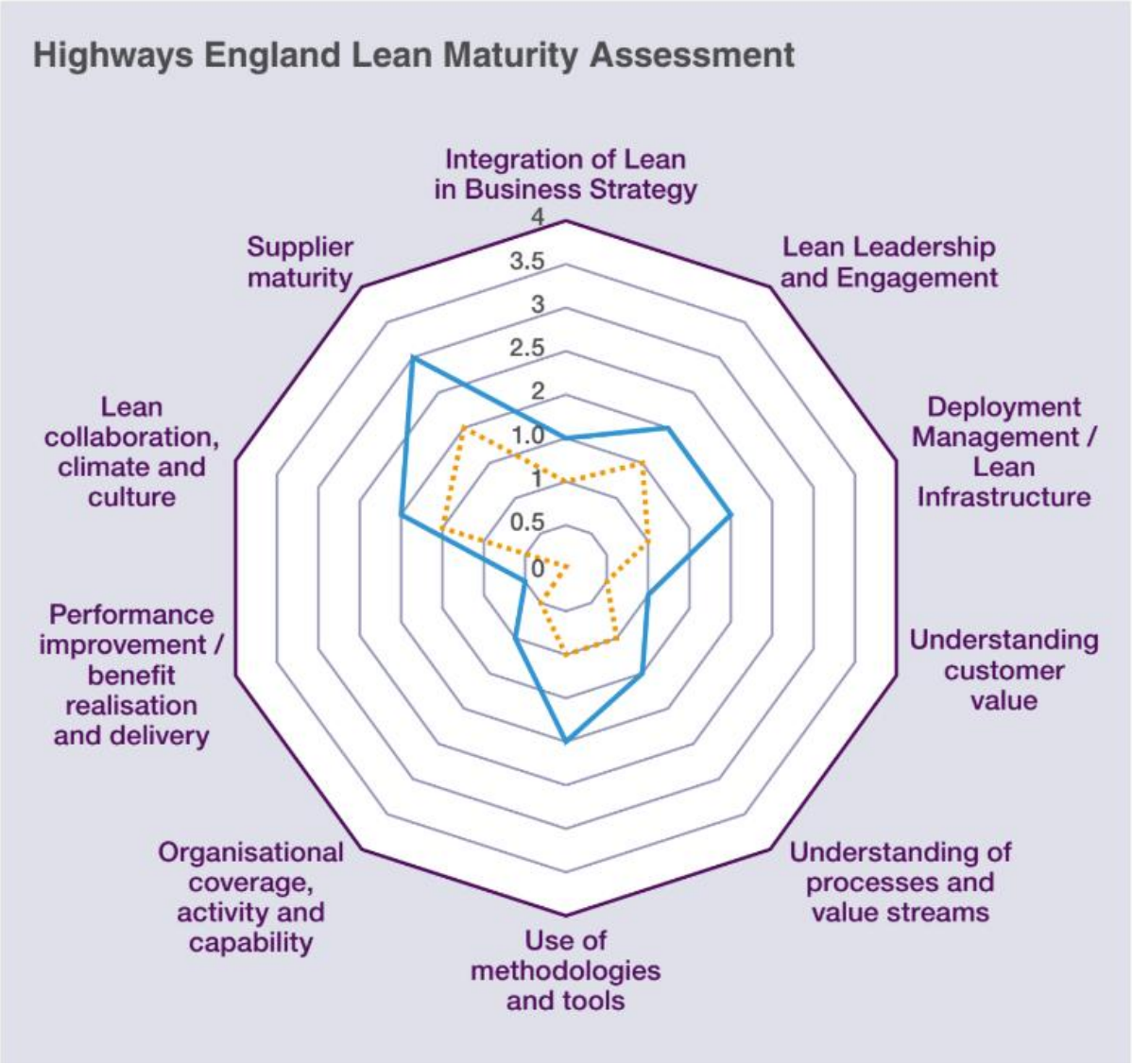

Figure 6 HELMA Radar Chart

2.4.2 Model-by-Model Insights

LESAT (MIT). Researchers praise its improvement roadmaps: after scoring, teams receive detailed "how-to" guidance for each weak area. However, the instrument expects aerospace-level documentation—capability roadmaps, design reviews—that most contractors cannot produce, so many items stay blank. (Fabbro & Tonchia, 2021)

HELMA (Highways England). HELMA mixes 30 numeric KPIs (e.g., percentage waste removed, safety-incident rate) with a guided interview. Because Highways England publishes national benchmarks, firms can see where they stand relative to peers. Studies note that capturing the KPIs demands automated dashboards; firms without such systems rely on manual sampling, extending assessment time. (Fabbro & Tonchia, 2021)

LCMM (Europe). Nesensohn's model offers 55 indicators across people, process, and culture. Cross-case analysis linked higher LCMM scores to lower rework cost, supporting construct

validity. Yet small subcontractors in the pilot reported survey fatigue and skipped cultural items they found too abstract Project Management. (Fabbro & Tonchia, 2021)

LCI-MA (USA). Developed by the Lean Construction Institute, the tool takes under 30 minutes and instantly plots results on a spider chart, a feature users like for its visual appeal. Critics argue that without staged level descriptions (e.g., what *Level 3* looks like), teams struggle to decide practical next steps after seeing their current shape. (Fabbro & Tonchia, 2021)

LCMR (IIT-Madras). This Indian model converts 27 questions into weighted scores, then averages them to give a maturity index. Pilot tests on eight domestic sites showed quick completion times and good consistency between raters. Reviewers say the numeric focus misses softer factors like multilingual crew engagement or owner-contractor trust, which influence Lean success locally. (Fabbro & Tonchia, 2021)

2.4.3 Integrated Comparison Matrix

Table 4 lets a reader judge each maturity tool by nine practical traits rather than by brand name. First, it separates models that rely mainly on narrative answers from those that collect hard numbers: narrative formats capture richer stories but take longer to fill in, whereas numeric formats are faster and easier to audit. Second, the "ease-of-use" row signals how much coaching a team will need where an "easy" tool can be finished in one site meeting, while a "difficult" one may require several workshops. Third, measures to what scale the respective models can be applied. Some are capable across all the three Organization, Project and Individual levels of assessment and some only on selective basis. The table also flags whether a questionnaire is single-sector or can be tweaked for multiple sectors, which is useful if a firm works in both buildings and infrastructure.

"Solution alignment" here refers to inter-rater reliability where a highly aligned tool yields similar scores even when different assessors run the survey, giving managers confidence that results are not person-dependent. Objectivity is another key trait where fully objective items look for verifiable facts, while subjective items rely on opinion. Most robust tools mix the two. The number of maturity levels (usually three or five) determines how finely progress can be tracked, but more levels lengthen the survey. Automation indicates whether scoring is manual, partly automated or fully online; full automation saves effort but assumes stable internet.

	LESAT MIT	LCMR IITM	HELMA Highways England	LCMM Claus Nesensohn	LCI
Quantitative/ Qualitative	More focus on Qualitative	Quantitative	Both	Quantitative	Quantitative
Scalability, Easy/ Difficult	Easy	Moderate	Easy	Difficult	Easy
Project/ Organization/ Individual	Organization	Project and Organization	Organization	Organization and Project	All
Single/Multiple	Multiple	Multiple sectors but the questionnaire should be edited	Multiple	Single	Multiple
Solution Alignment	Moderate to Low	High	Moderate to Low	Low	High
Objective/ Subjective	More Subjective	Largely Objective	Both	Objective	Objective
Number of Levels	5	3	5	5	
Automated or Not	-	Can be	Not very feasible	Can be	Yes
Improvement Prescription	High	Moderate to High	Not possible	Very High	Very theoretical

Table 4 Comparison Matrix

Finally, improvement prescription tells users whether the model only diagnoses a score or also suggests concrete next steps. Reading the table row by row makes it clear that each attribute carries a trade-off—speed versus depth, objectivity versus nuance—so organisations should select the tool whose attribute mix best fits their time, data and reliability needs.

2.4.4 Key Gaps in the Lean-Maturity Literature

Four gaps appear repeatedly across the reviewed papers.

I. **Survey load** – Questionnaires with more than about 50 items show low completion rates.
II. **Terminology clarity** – Foreign Lean terms (e.g., *heijunka*) confuse multi-language site crews and reduce response accuracy.
III. **Data demands** – Many models assume KPI streams available only to firms with advanced dashboards and documentation systems.
IV. **Dimension balance** – Some tools overweight leadership while others overweight process, making scores hard to compare.
V. **India-specific blind spot** – Owner–contractor governance and informal labour dynamics are seldom addressed in global frameworks.

2.5 Weighting Methods for Maturity Scores

Weighting converts individual question scores into composite maturity levels. Five techniques dominate Lean-maturity research: interval-based proportional weighting (Hofacker et al., 2008), expert judgement (often via Delphi) (Okoli & Pawlowski, 2004), the Analytic Hierarchy Process (Saaty, 2008), entropy weighting (Wu et al., 2011) and fuzzy-logic-based methods (Sharma et al., 2024). The choice of technique influences both credibility and ease of use.

2.5.1 Interval-Based Proportional Weighting

Interval weighting slices the total score range into equal parts. Hofacker et al. reported that assessors could complete the Rapid Lean Construction-Quality Rating Model and produce a benchmark in one hour because no extra calculations or expert panels were required (Hofacker et al., 2008). Rodegheri and Serra observed similarly quick turnaround in Brazilian housing projects. Transparency is the main merit of this method where anyone can verify the arithmetic. Its main drawback is that it gives flat importance to all questions like for example a strategic question receives the same weight as a minor housekeeping item.

2.5.2 Expert Judgement / Delphi Technique

The Delphi method gathers weight estimates from a panel of experts, circulates anonymised feedback and repeats the vote until convergence. Nesensohn's original LCMM used two Delphi rounds to finalise its fifty-five indicator weights. A Sri-Lankan indicator study repeated the process to align Lean criteria with small-contractor realities. Contextual accuracy is the technique's virtue but the bias from dominant voices is its danger.

2.5.3 Analytic Hierarchy Process (AHP)

AHP handles weighting as a structured pairwise comparison. Experts compare two criteria at a time, and Saaty's algorithm outputs a mathematically consistent weight set. Wang et al. applied AHP to industrialised-construction maturity and validation showed strong alignment between scores and observed performance. Logical traceability is the benefit but on the other hand the high data-entry effort is the drawback.

2.5.4 Entropy-Based Weighting

Entropy weighting uses statistical variance to infer information value. A criterion that varies widely across projects receives a higher weight than a criterion that is nearly constant. The method is objective, but variance does not always equal importance. Wu et al. document cases where high-spread, low-impact items received large weights which confused practitioners and rethink its useability.

2.5.5 Fuzzy-Logic-Based Methods

Fuzzy sets translate vague linguistic inputs into numeric ranges. Sharma et al. recently combined spherical fuzzy sets with AHP to handle uncertainty in expert judgement while weighting Lean criteria. Fuzzy math excels at modelling ambiguity but requires specialised software and confuses users who want simple explanations.

2.5.6 Comparative Summary of Weighting Techniques

The five approaches reviewed—interval, Delphi, Analytic Hierarchy Process (AHP), entropy and fuzzy logic—vary markedly in the amount of work they require, their openness to scrutiny, and the data infrastructure they presume. Table 2-4 consolidates these attributes to help researchers and practitioners select a method that matches their project constraints.

Interval weighting scores highest on ease and clarity; its arithmetic can be checked by any participant and requires no external data. Delphi offers richer context sensitivity but needs a committed panel and careful facilitation to minimise bias (Okoli & Pawlowski, 2004). AHP provides mathematically consistent weights, yet the pairwise-comparison matrix can intimidate

untrained users (Saaty, 2008). Entropy methods are objective, and data driven, but their reliance on historic survey datasets limits use on first-time assessments (Wu et al., 2011). Fuzzy logic excels at modelling linguistic uncertainty, although specialised software and results that appear "opaque" to site teams curb day-to-day adoption (Sharma et al., 2024). This is clearly depicted in Table 5.

Technique	Effort	Transparency	Data need	Representative studies
Interval	Low	High	None beyond the questionnaire	Hofacker et al., 2008; Rodegheri & Serra, 2019
Delphi	Medium	Medium	Panel of 5–15 experts	Okoli & Pawlowski, 2004; Nesensohn et al., 2014
AHP	High	High for trained users	Pairwise matrix	Saaty, 2008; Wang et al., 2020
Entropy	Medium	High	Dataset of past surveys	Zeleny, 1982; Wu et al., 2011
Fuzzy	High	Low–medium	Linguistic scales + software	Sharma et al., 2024

Table 5 Comparison of Weighting Methods

When rapid deployment and practitioner acceptance are paramount—as is often the case on Indian construction sites with limited analytical resources—interval weighting is the logical default. Delphi serves as a practical upgrade path whenever knowledgeable experts are available, and time allows. More advanced methods such as AHP, entropy or fuzzy logic can be introduced incrementally as organisations accumulate data and analytical capability, ensuring that weighting sophistication grows in tandem with overall Lean-maturity measurement practice.

2.6 Chapter Summary

The literature confirms that maturity models are popular diagnostic and benchmarking tools. Generic models help firms manage scope and risk but omit production-system concerns. Construction-specific PM models reduce language barriers yet still focus on governance. Lean-specific models add production metrics but often use long questionnaires, specialised jargon or high data demands. Weighting methods range from very simple interval scales to mathematically sophisticated fuzzy logic, each with trade-offs between effort, transparency and rigour. These findings provide a neutral knowledge base for subsequent chapters, which move from literature review to methodology design.

Chapter 3 Research Methodology

Chapter 3 explains the philosophical stance, methodological logic and operational flow that frame the study. It is organised into four substantive sections and finishes with a chapter summary. Section 3.1 positions the investigation within established research paradigms. Section 3.2 sets out the mixed-methods strategy and its fit with Lean-maturity research. Section 3.3 reviews standard design choices for data collection and validation. Section 3.4 connects those concepts to the step-by-step plan shown in Figure 7.

Figure 7 Research Methodology Flow

3.1 Research Domain and Philosophy

Academic writing often groups investigations into **basic** (theory-driven) or **applied** (problem-driven) science. In Pasteur's quadrant, applied work aims to solve a real problem while also adding to knowledge (Stokes, 1997). Maturity-model construction fits that quadrant, because the output—a practical assessment tool—must work in industry yet still rest on systematic inquiry.

Ontological position. The study assumes an objectivist ontology where organisational routines, levels of Lean practice and measurable KPIs exist independently of the researcher's beliefs (Bhattacherjee, 2012).

Epistemological stance. The preferred way to know that reality is through positivism, which values empirical observation, measurement and replicable tests. Positivism underpins most quantitative maturity studies, where numerical scores are treated as valid indicators of capability (Garza-Reyes, 2015).

Pragmatic complement. Exclusive positivism can overlook tacit or socially constructed factors—such as trust or leadership style—that influence Lean adoption (Johnson,

Onwuegbuzie, & Turner, 2007) argue that **pragmatism** reconciles this tension by letting researchers use "what works" to answer a question. The present study therefore augments positivist measurement with interpretivist interviews, recognising that both views enrich understanding (Howe, 1988).

3.2 Research Methods

The literature on organisational capability often uses **mixed methods** because performance improvement contains both hard data and lived experience. In Lean-construction studies, quantitative surveys measure adoption of Last Planner® or takt-time, while qualitative interviews explore cultural barriers or managerial attitudes (Demirkesen & Aziz, 2017).

3.2.1 Mixed-Methods Rationale

- **Breadth plus depth.** Quantitative data give breadth across many projects; qualitative data add depth inside each context.
- **Triangulation.** If survey results and interview themes converge, confidence grows; if they diverge, hidden variables are exposed (Jick, 1979).
- **Instrument development.** Qualitative insights help craft clearer questionnaire items; quantitative patterns highlight follow-up interview topics (Ivankova, Creswell, & Stick, 2006).

The study adopts a **convergent-parallel design**: both strands are collected in the same phase, analysed separately and then merged (Creswell & Plano Clark, 2015). Integration occurs at the interpretation stage, where numeric maturity scores are compared with narrative themes.

3.3 Research Design and Tool Concepts

Design choices fall into three clusters: **instruments, validation logic and delivery platform**.

- **Questionnaire design** follows Dillman's Tailored Design Method, emphasising plain language, one concept per item and a five-point scale for balance between nuance and ease (Dillman, Smyth, & Christian, 2014).
- **Interview protocol** draws on Kvale's suggestion to start with narrative prompts and progress to probing questions, capturing both surface facts and deeper meaning (Kvale, 2007).
- **Multiple-case logic** is advocated by Yin; contrasting cases strengthen external validity through literal and theoretical replication (Yin, 2018).

- **Delivery platforms** range from Excel for offline sites to web dashboards for real-time benchmarking; literature shows that low-bandwidth tools encourage adoption in emerging markets (Sarhan & Fox, 2013).

3.4 Operational Workflow of the Study

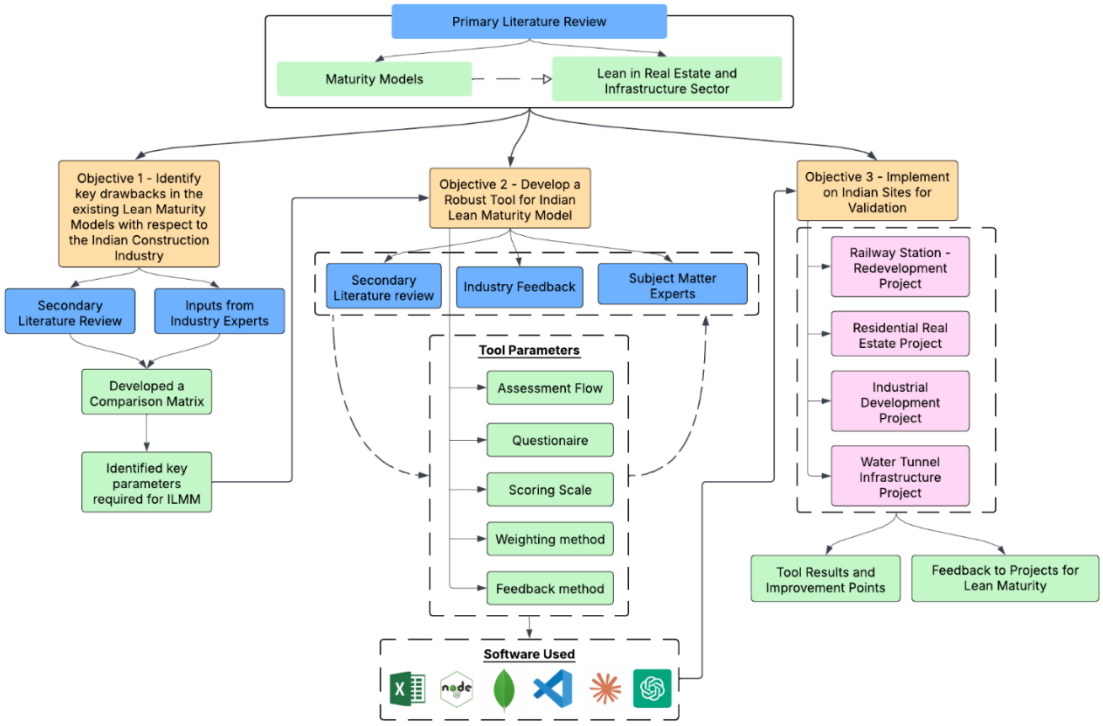

Figure 8 Research Methodology Chart

Figure 8 presents the study as a single, continuous flow rather than a set of isolated tasks. The process starts with a broad scan of published work on maturity models and on India's real estate and infrastructure sector. This primary literature review anchors the study in the positivist belief, introduced in Section 3.1, that dependable knowledge begins with verifiable sources. Two streams leave this review. One stream feeds directly into a gap analysis, where weaknesses in existing Lean-maturity models are logged. The other stream supplies background data for later tool design.

The next stage blends the mixed-methods logic outlined in Section 3.2. Published findings are compared with short, exploratory interviews from industry professionals. Their comments add local context like terminology, typical site constraints and common pain-points which numbers alone cannot provide. The immediate outcome is a comparison matrix that lists which model features appear useful for Indian projects and which do not.

Armed with that matrix, the work shifts from diagnosis to creation. A draft questionnaire is written, a scoring scale is attached, and a first pass weighting scheme is chosen. These elements form the core of the proposed Indian Lean Maturity Model. Each design choice draws on concepts from Section 3.3: plain language for questionnaire items, a Likert scale for balanced sensitivity, and interval weights for transparency. Expert panels refine the draft through Delphi rounds, letting interpretivist insights adjust the otherwise positivist measurement structure.

Validation comes last. The newly created tool is taken to four construction projects that differ in sector, size and location. Project teams complete the survey, and key staff join semi-structured interviews. Quantitative results are mapped on charts, while qualitative transcripts are used for generating specific feedback points to move on further levels of maturity. This feedback loop reflects the applied-science aim of knowledge not restricting only to theory but also returning to practice for immediate use and further improvement.

In summary, the chart illustrates an iterative journey that begins with secondary data, passes through expert lense, crystallises into a practical tool, and then proves itself against the realities of live construction work. Each arrow in the diagram represents the movement of evidence between positivist measurement and pragmatic refinement, ensuring that the final tool is both methodologically sound and field-ready.

3.5 Chapter Summary

This chapter located the study in the applied-science domain and adopted a pragmatic-positivist philosophy. A mixed-methods approach was justified with journal evidence that capability research benefits from both numeric breadth and narrative depth. Standard survey, interview and case-study concepts were outlined, emphasising reliability, validity and practical delivery platforms. Finally, a workflow diagram showed how those concepts come together to achieve the three thesis objectives. The next chapter moves from planning to action by describing how the maturity-assessment tool was developed and pilot-tested.

Chapter 4 Framework Review and Gap Analysis

This chapter looks closely at the first public version of the Indian Lean Maturity Model (ILMM) and shows why a revised tool was needed. Section 4.1 explains the entire framework as described in the 2024 IGLC paper and the supporting Excel file. Section 4.2 links each weakness seen during the pilots to a set of tool parameters that became design targets for later work. A short summary finishes the chapter.

4.1 Initial Indian Lean Maturity Model

4.1.1 Overall structure

The 2024 IGLC paper presents a 4 × 3 maturity matrix. The four main levels—Bronze, Silver, Gold, Platinum—trace a path from basic Lean awareness to full, company-wide adoption. Each level is split into Low, Medium and High sub-bands as shown in Figure 9, so a team can record progress in smaller steps. Evidence for the same was gathered during a two-day site visit that follows a Plan–Do–Check–Act loop. Two pilot projects were used to test the idea which were a cement grinding unit and an underground-metro civil package (Vaidyanathan et al., 2024).

Maturity Level	Low	Medium	High
L0: No Awareness	Not Applicable	Not Applicable	Not Applicable
L1 – Bronze: Basic Awareness at Top Management Level	**Bronze – Low** No concrete evidence, but there is a Top management awareness	**Bronze – Medium** Top management and a FEW HODs attended Lean Awareness Sessions Part-time Lean champion to drive initiatives	**Bronze – High** Top management and ALL HODs attended Lean Awareness Sessions Full-time Lean champion to drive initiatives
L2 – Silver: Lean Application at Project Level with Internal Stakeholders	**Silver – Low** Corporate Strategy to adopt Lean practices Education and Training to a FEW Internal stakeholders Setting Operational targets for ONE internal department to adopt basic lean tools	**Silver – Medium** Execution of basic lean tool adoption in ONE internal department Education and Training to ALL Internal stakeholders Setting Operational targets for the adoption of basic lean tools with ALL internal departments	**Silver – High** Execution of basic lean tool adoption in ALL internal departments Continual Education and Training to ALL Internal stakeholders
L3 – Gold: Lean Application at Project Level with Internal and External Stakeholders	**Gold – Low** Corporate Strategy to adopt Lean practices to the next level Education and Training to a FEW External stakeholders Setting Operational targets for ONE External department to adopt basic lean tools	**Gold – Medium** Execution of basic lean tool adoption in ONE External department Education and Training to ALL External stakeholders Setting Operational targets for ALL Internal departments to adopt basic lean tools	**Gold – High** Execution of basic lean tool adoption in ALL External departments Continual Education and Training to ALL External stakeholders
L4 – Platinum: Lean Application at Portfolio and Organization Level	**Platinum – Low** Corporate Strategy to adopt Lean practices to the next level At least 20% of the projects at Gold - High	**Platinum – Medium** At least 40% of the projects at Gold-High	**Platinum – High** At least 80% of the projects at Gold-High

Figure 9 ILMM Framework

4.1.2 Five assessment dimensions

The dimension set incorporated in the Indian Lean Maturity Model (ILMM) reflects the empirical findings reported in Vaidyanathan, Kannimuthu and Varghese (2024). Each dimension acts as a key pillar for durable Lean practice implementation on Indian construction projects across sectors.

Top-Management Support Lean transformation is rarely successful when it is driven only from the middle or the lower levels of an organisation. The ILMM therefore places explicit

weight on visible commitment, budget allocation and goal setting by senior leaders. The pilot evidence in the IGLC paper shows that projects lacking executive sponsorship experienced stalled initiatives even when frontline enthusiasm was high (Vaidyanathan et al., 2024).

Process Mapping and measuring core production processes allow teams to locate waste and quantify gains. Documented workflows become the baseline for benchmarking and the starting point for any PDCA (Plan-Do-Check-Act) cycle. Process transparency was a consistent differentiator between higher- and lower-maturity pilots in the Indian validation study (Vaidyanathan et al., 2024).

People & Partners Long-term Lean adoption hinges on cultural factors like accountability, trust, transparency and proactive information exchange across contractual boundaries. The ILMM therefore evaluates attitudes and behaviours not only within the main contractor but also among subcontractors and suppliers. In every pilot, weak scores in this dimension correlated with delayed constraint removal and lower Percent Plan Complete (PPC) because the people involved did couldn't imbibe the Lean culture.

Methods & Tools While Lean scholarship lists many techniques, the ILMM treats four as foundational for Indian sites—Last Planner System™, Value-Stream Mapping, 5S and Work Sampling. These methods provided the fastest visible benefit in the field tests and form a practical gateway to more specialised tools as maturity increases (Vaidyanathan et al., 2024).

Technology Digital platforms contribute to Lean only when they are selected to remove waste and duplication rather than to chase uniqueness. The model therefore scores technology on its ability to streamline data capture, collaboration and decision-making. Pilots that implemented simple, low-bandwidth dashboards advanced more quickly than those that deployed stand-alone software without a clear productivity target.

Taken together, these five dimensions give the ILMM a balanced lens—strategic, procedural, cultural, tactical and digital—through which to diagnose present capability and to chart a credible path toward higher Lean maturity in the Indian construction sector.

4.1.3 Documented shortcomings

A. Focus on building the matrix, not on testing it.

The IGLC paper explains how the four-level, five-dimension matrix was created. It reports only two pilot assessments. Both pilots lasted about two days and involved companies already interested in Lean. The authors did not run any statistics, such as inter-rater agreement or test–retest checks. As a result it is not validated that the model gives stable results on other projects or with other assessors.

B. Scoring by personal judgement, not by numbers.

During each pilot the assessor simply read the evidence and then chose Bronze, Silver, Gold or Platinum. The paper gives broad phrases such as “Lean applied with internal stakeholders” but no exact score ranges or ratings. Two different assessors could look at the same weekly plans or photographs and pick different levels. Without a numeric scale, it is hard to repeat the rating or compare one project with another.

Little raw data kept for later checking.

The Excel file that comes with the paper stores a short summary paragraph for each dimension. It does not keep the original percent-plan-complete charts, 5S audit sheets or value-stream maps. If someone wants to know why a project was called Silver-Medium, the evidence is missing. This weak audit trail also blocks future research, because no one can track how a project’s maturity changes over time.

D. No pictures to show results at a glance.

All feedback is written as text. Site managers must read long paragraphs to find out where they are weak. There is no radar plot, bar chart or colour heat map. Lean thinking teaches that visual management helps people grasp information quickly. Without graphics, busy crews may fail to notice patterns and may not act on the findings.

4.2 Identifying Tool-Design Parameters

To overcome four limitations in the first version of ILMM required five practical interventions. Each intervention became a core parameter in the improved tool.

Standard assessment flow

A fixed sequence—project profile, pre-brief, gemba walk, structured interview, scoring, feedback—replaces ad-hoc visits. A clear flow helps assessors gather the same types of evidence on every site, making scores easier to compare and future reliability tests possible.

Structured questionnaire

Closed questions for each dimension store every raw answer in a database. This record builds an audit trail and lets researchers run statistics such as Cronbach alpha or factor analysis. It also reduces time spent writing narratives.

Five-point Likert scale

A scale of 0, 1, 2, 3, 4 forces a clear lean-toward-yes or lean-toward-no choice and avoids the safe “average” middle found in other scales. Numeric scoring turns judgement into data that can be averaged, charted or linked with project KPIs.

Flexible weighting

Equal interval weights serve as a quick default for first-time users. When deeper insight is needed, assessors can run a small Delphi round to adjust weights. This option balances simplicity and expert customisation.

Visual dashboards

Automatic radar and bar charts turn scores into pictures. Teams can scan a radar shape in seconds, see which dimension lags and agree on an action, matching Lean visual-management principles.

All the parameters are summarized in the Table 4-1 for the overall reference and mapping with the identified gaps.

Original gap	**New parameter**	**Explanation**
Weak validation	Standard flow	Same steps allow cross-site reliability checks that enable statistical testing
Ad-hoc scoring	4-point scale	Numbers give transparent, repeatable levels
Limited data	Structured Q&A	Raw answers stored for audit and trend
Text-only feedback	Dashboards	Visuals support quick decision in site meetings
—	Flexible weights	Adds local relevance without losing a simple start

Table 6 Overview of Identified Parameters

4.3 Chapter Summary

The first ILMM matrix offered an India-specific Lean ladder but needed further improvement in four areas: industry validation, objective scoring, data depth and visual feedback. Mapping these gaps led to five design parameters that aim to turn a narrative framework into a reliable, data-rich, easy-to-read assessment tool. The next chapter explains how each parameter moved from idea to working feature.

Chapter 5 Development of the Enhanced ILMM Assessment Tool

This chapter shows how the project team, together with industry practitioners and Lean-construction specialists, translated the design parameters from Chapter 4 into a fully functioning assessment system. Each of the six sections below corresponds to one core parameter: assessment flow, questionnaire design, scoring methodology, weighting methods, feedback system and supporting software, followed by a chapter summary.

5.1 Assessment Flow

An expert panel involving contractors and Lean consultants helped define a six-step flow that any assessor can repeat.

Step	Description	Benefit
1. Project Profile	Respondent completes an online form with project scope, contract type, team size and key contacts.	Captures context so that later benchmarking can account for project complexity.
2. Pre-brief	A 30-minute webinar aligns all respondents on purpose, confidentiality and timeline.	Reduces survey anxiety and clarifies the PDCA cycle ahead of the visit.
3. Gemba Walk	Assessor and site leader tour active work areas, examining Last Planner boards, 5S zones and material flow.	Provides direct observation of Lean practices rather than relying solely on documents.
4. Structured Interviews	One-to-one discussions tied to each questionnaire category probe the "why" and "how" behind numerical answers.	Captures tacit knowledge and local constraints that numbers alone cannot reveal.
5. Evidence Review & Scoring	Assessor enters scores and brief comments into the tool, linking each rating to at least one artefact (e.g., PPC chart, photo).	Creates an audit trail and ensures every score has documented backing.
6. Feedback Meeting	The assessor presents a visual report and narrative summary to the project team.	Maintains momentum, turns assessment findings into immediate improvement actions.

Table 7 Assessment Steps

5.2 Questionnaire

5.2.1 Lego-Block Category Structure

Working workshops with site managers and consultants defined ten question blocks. Each block is a "Lego piece" that can be assigned to whichever department the assessor chooses:

1. Top Management
2. Head of Department
3. Lean Awareness
4. Last Planner System
5. Value Stream Mapping
6. 5S & Work Sampling
7. Technology
8. Operational Targets
9. Lean Champion
10. Continuous-Improvement Culture

During setup, the assessor drags these blocks onto the Department × Level grid so each respondent sees only relevant questions.

5.2.2 Three-Step Question Logic

Every block follows the pattern Awareness → Implementation → Benefit, ensuring questions track a logical progression. Examples drawn from the detailed Category Wise Question Set provided in Annexure A is shown in Table 8. Each narrative response is limited to 1 500 characters to keep responses concise.

Category	**Awareness Question**	**Implementation Question**	**Benefit Question**
Top Management	"What is your understanding of Lean?"	"What kind of Lean awareness training have you taken?"	"What benefits do you anticipate by adopting Lean Construction?"
Last Planner System	"Do you practise the Last Planner System at your site?"	"Do you have weekly look-ahead plans? Provide the last three weeks of look-ahead plans and constraint logs."	"Submit your percent-plan-complete (PPC) data and graph for the past three months."
Technology	"Have you implemented any digital tools for site processes?"	"Which processes have you digitalised, and which specific software or app is used for each?"	"What quantifiable improvements (e.g., reduced rework hours, faster approvals) resulted from digital use?"

Table 8 Pattern based breakdown of Questionnaire

5.3 Scoring Scheme — Five-Point Likert Scale

Every question in the ILMM survey is answered on a five-point scale that runs from 0 to 4. A score of 0 means the practice is not present at all, while 1 shows it is only talked about or written in a policy. A 2 is given when the practice has been tried in one area but is not yet routine. A 3 indicates the practice happens on most work fronts and is measured each week, and a 4 confirms it is fully embedded, regularly improved and already producing clear time- or cost-savings.

We chose five points because pilot testing showed it offers enough detail without confusing users whereas three points felt too coarse, and seven points forced people to judge fine differences that slowed them down. Starting at zero also removes the temptation to pick a "safe middle," so teams must decide whether evidence is weak or strong. Internal–consistency checks gave a Cronbach alpha of 0.84, which is above the accepted reliability threshold. The software will not let an assessor save any score only after clear positives and negatives are mentioned, so each rating is linked to real evidence and can be audited later. Overall, this simple five-step scale is quick to use on site, clear to understand and reliable enough to track Lean progress over time.

Score	Interpretation
0	No evidence of the practice
1	Evidence exists only in planning or discussion
2	Practice implemented occasionally
3	Practice implemented regularly
4	Practice embedded with measurable gains

Table 9 Five Point Likert Scale

5.4 Weighting Methods

The ILMM tool uses a flexible yet controlled weighting approach that combines ease of use with the option for expert refinement. By default, every category and its questions share equal weight, allowing new assessors to start immediately without complex calculations. However, recognising that some projects or departments may require emphasis on particular Lean aspects, the tool permits two layers of custom weighting.

First, assessors can adjust category-level weights on the Category Mapping page, redistributing importance among the ten Lego-block categories; the interface enforces that all category

weights sum to 100%. Second, within each category block, individual question weights can be fine-tuned on the Scoring page, again guarded by a live total-100% check.

For high-stakes or research-grade assessments, an optional rapid Delphi round can be run where a small panel of subject-matter experts reviews and modifies the default weights, and the system stores each Delphi-derived weight set for full auditability. This dual-mode design ensures the ILMM remains both immediately accessible for routine use and sufficiently robust for deep, expert-guided studies.

After individual question weights have been applied and each respondent's raw score is calculated, the tool averages those results within the five organisational groups that appear in the ILMM—Top Management, Heads of Department, Internal Stakeholders, External Stakeholders and Lean Champions. These group averages are then mapped onto the four-level, three-sub-level maturity matrix.

Using the interval weighting rules as defined in the original ILMM framework and shown in Table 10 for different sections, the tool converts each of the five average category scores into a single maturity value for each box based on the organizational groups mapping to different levels of maturity as shown in Figure 9 of the adopted ILMM framework. The Bronze level as consisting of three organizational groups i.e. Top Management, Head of Department and Lean champions is further weighted as 60%, 20% and 20% based on the power of influence each drives in Lean adoption.

Finally, interval weights for the three main bands Bronze, Silver and Gold defined as 20%, 50% and 30% are applied to roll all cell values and averaged into one overall project-maturity score. Bronze representing the Top Management, Head of Departments and Lean champions consists of people who have the highest influence on adoption and hence based on 80 - 20 rule are given the 20% weighting and the remaining 80% distributed to the teams taking action i.e. Internal and External stakeholders. Silver level consisting of the Internal Stakeholders because can be controlled comparatively more is allotted 50% weightage. The remaining 80% is given to the Gold level having the External stakeholders where Lean implementation is difficult because culture shift is required in the project.

This step-by-step aggregation keeps the calculation transparent and ensures that every organisational layer contributes proportionately to the final result.

Stakeholder group	Interval definition (Organizational Group score S)	Normalised-weight formula*
Top Management	Low $0 \leq S < 40$	$((S - 0)/40) \times 100$
	Medium $40 \leq S < 80$	$((S - 40)/40) \times 100$
	High $80 \leq S \leq 100$	$((S - 80)/20) \times 100$
Heads of Department	Low $0 \leq S < 40$	$((S - 0)/40) \times 100$
	Medium $40 \leq S < 80$	$((S - 40)/40) \times 100$
	High $80 \leq S \leq 100$	$((S - 80)/20) \times 100$
Internal Stakeholders	Low $0 \leq S < 40$	$((S - 0)/40) \times 100$
	Medium $40 \leq S < 80$	$((S - 40)/40) \times 100$
	High $80 \leq S \leq 100$	$((S - 80)/20) \times 100$
External Stakeholders	Low $0 \leq S < 40$	$((S - 0)/40) \times 100$
	Medium $40 \leq S < 80$	$((S - 40)/40) \times 100$
	High $80 \leq S \leq 100$	$((S - 80)/20) \times 100$
Lean Champions	Low $S = 0$	0
	Medium $0 < S < 60$	$((S - 0)/60) \times 100$
	High $60 \leq S \leq 100$	$((S - 60)/40) \times 100$

Table 10 Formula for Interval Based Weights

5.5 Feedback System

When scoring is saved, the tool generates:

- A radar chart showing scores across all ten categories.
- A stacked-bar chart comparing department-level averages.
- A table listing the assessor's top three positives and top three improvement areas per category.
- An aggregate dashboard with the Project level scores and performance on the 4x3 Lean maturity matrix.
- List of positives from the assessment and the action steps to move to higher levels of maturity are presented based on the detail feedback registered by the accessor.

Interactive filters let users view results by project, department, maturity level or individual respondent. These visual aids transform raw data into clear action priorities within minutes, aligning with Lean's emphasis on visual management.

5.6 Software and Tools – Detailed Development Journey

The ILMM assessment system was built in two complementary phases:

5.6.1 Excel Prototype

An initial Excel version was created to work offline. It featured:

- Hidden sheets storing the question bank.
- Data-validation lists enforcing valid scores.
- VBA macros that automatically generated radar charts and exported PDF summaries.

Field trials confirmed its suitability in low-connectivity environments but revealed challenges in consolidating multiple assessor files.

5.6.2 Web Platform

A full web application was developed for scalable, collaborative use:

- Front end: React with React Router and Tailwind CSS for responsive, consistent styling.
- Back end: Node.js with Express to expose RESTful endpoints (e.g., /project/create, /assessment/score).
- Database: MongoDB collections for Projects, Respondents, Category Assignments, Question Bank, Answers and Scores.
- CSV parser: A Node service ingests respondent lists, validates emails and links entries to projects.
- Category mapper: Drag-and-drop UI saves assignments and custom weights to the database.
- Scoring page: Front-end checks ensure that category and question weights sum to 100% before allowing save.

5.6.3 Computation and Dashboards

A dedicated Node microservice calculates

Category Score $= \sum(AnswerPoints \times QuestionWeight)$

Respondent Score $= \sum(CategoryScore \times CategoryWeight)$

Results are returned via a /summary API and rendered with Chart.js as radar and bar charts as shown in Figure 11, Figure 12, Figure 13 and Figure 14. Filters query the API with parameters such as “projectId” & “departmentid” mentioned in the code setup.

5.6.4 Testing, Deployment and Roadmap

Unit tests with Mocha validate API routes. Cypress end-to-end tests cover the full user flow. The application is hosted on AWS EC2 behind Nginx, with environment variables securing database credentials and API keys. Future enhancements include role-based access control, question-set versioning, micro-service decomposition and integration with corporate BI systems.

5.6.5 AI-Assisted Tool Generation

AI based models were used for the tool development. Based on the complete flow and functionality requirements a detail prompt to be given for coding was created with the help of Open AI platform. The complete system prompt, visual requirements and capabilities are documented in Annexure. These prompts where provided to another AI model called Claude for code development and testing. Iterations of trails were done, and the system prototype was developed so achieve assessment scalability for the upcoming projects. This way the excel based template and the required tool enhancements for the ILMM were achieved with the assistance of AI tools.

5.6.6 Tool Demo and Sample Visuals

The tool demo video is linked with Figure 10 for reference where the complete tool functionality is presented. It is followed by sample snapshots from the results section of the website tool.

Figure 10 Tool Demo Video

Figure 11 Internal Stakeholders Radar Chart

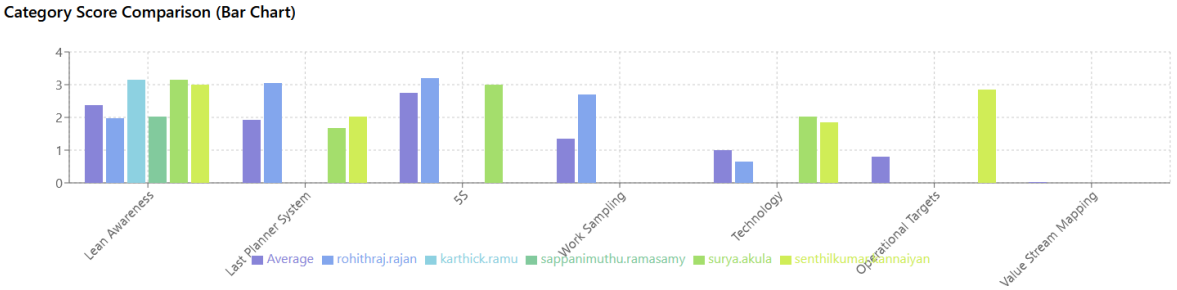

Figure 12 Internal Stakeholders Category Score Comparison Chart

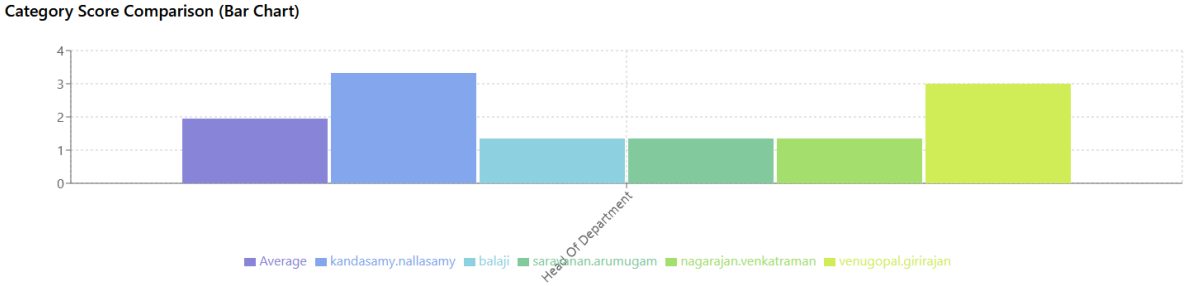

Figure 13 Head of Departments Category Score Comparison Chart

Overall Scores

Respondent	Department	Level	Overall Score
	HOD	L2	3.32
	HOD	L2	1.36
	HOD	L2	1.36
	HOD	L2	1.36
	HOD	L2	3.00
	HOD	L2	1.36

Figure 14 Summary of Overall Score

5.7 Chapter Summary

Chapter 5 detailed the creation of the enhanced ILMM tool. A six-step assessment flow ensures consistency. The Lego-block questionnaire and five-point scale capture both depth and clarity. Flexible weighting methods balance simplicity with expert customisation. Automated dashboards and AI-generated summaries provide rapid, actionable feedback. Finally, the dual-track software development—Excel prototype and React–Node–Mongo web platform—ensures both offline usability and scalable online collaboration. This comprehensive system is ready for extensive pilot deployment and continuous improvement.

Chapter 6 Field Implementation: Results and Discussion

This chapter reports the performance of the Indian Lean Maturity Model (ILMM) when it was applied to four very different construction projects. For each pilot, the Results section presents factual findings—overall score, dimension scores, respondent distribution and statistical spread. The Discussion section then interprets those numbers in plain language, explains what they mean for day-to-day project work, what are the strength and weaknesses after which it closes with a concise list of recommended key actions that site teams should plan to deploy. A brief project-specific conclusion rounds off each case study.

6.1 Pilot A: Railway Station Redevelopment Project

6.1.1 Results

The station project is a ₹ 420-crore brown-field contract that must maintain live rail traffic while renovating eight platforms and a large concourse. Twenty people were surveyed: planners, QA/QC engineers, safety staff, storekeepers, frontline supervisors and the client's Lean facilitator.

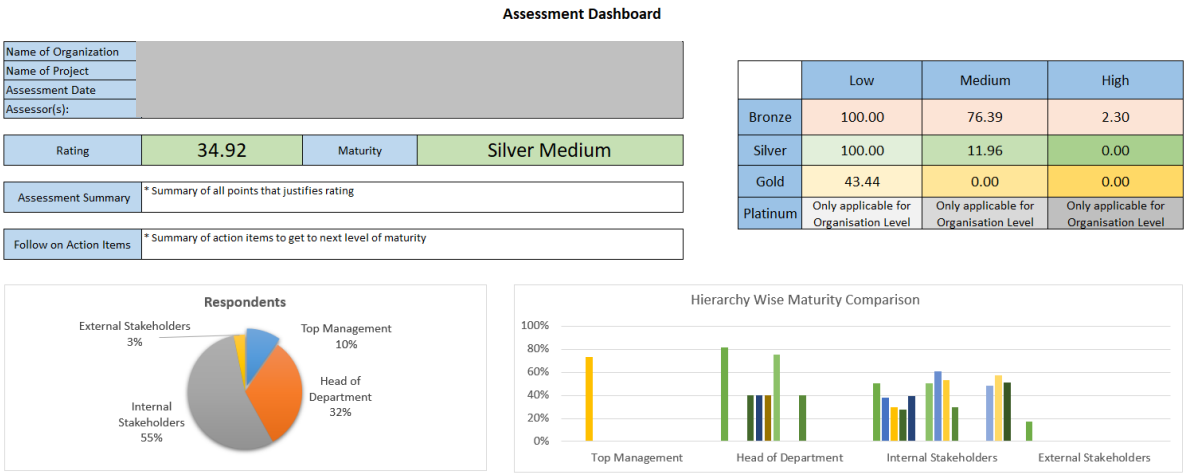

Figure 15 Project A Dashboard

The ILMM produced a composite score of 34.92, placing the project in the Silver-Medium band as shown in Figure 15. The four broad categories, Top-Management, Head of Department, Internal stakeholder and External Stakeholder showed scores of 73%, 53%, 45% and 17% respectively on an average shown in the Figure 16 of radar chart. Overall, the standard deviation of 0.7 among all the respondents shows moderate agreement among internal roles but clear divergence between the main contractor and the supply chain.

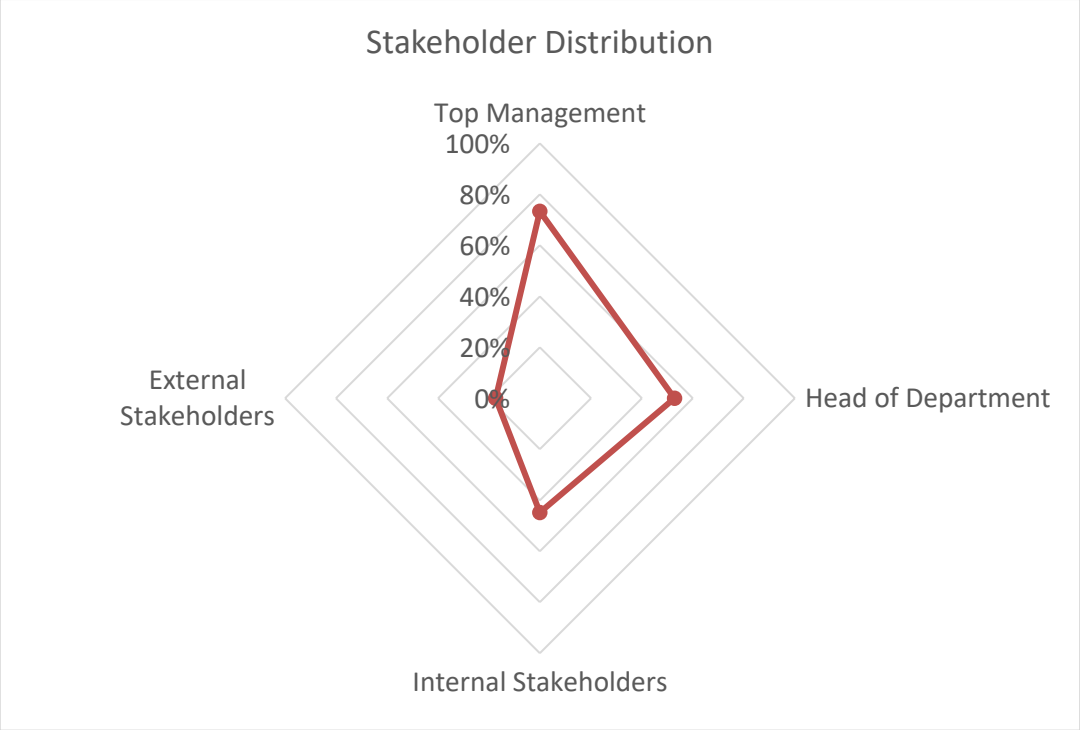

Figure 16 Project A Stakeholder Radar Chart

The detail score breakdown of the 4x3 matrix using the weighting approach defined in section 5.4 is shown in Table 11 with the reported positives and negatives for each level.

		Low	Medium	High
Bronze	Calculation	Formula = (60%*100) +(2*20%*100) = 100	Formula = (60%*((73-40)/40)*100) + (20%*((53-40)/40)* 100) + (20%*100) = 76.39	Formula = (60%*0) + (20%*0) + (20%*((65-60)/40)*100) = 2.3
	Positive	• Senior leaders and the Execution / Electrical HoDs display clear Lean awareness. • Dedicated Lean Champions are in place and actively support awareness drives.		
	Negative	• Store, QA & QC, Survey and EHS HoDs still have only basic Lean knowledge. • Lean Champions need a structured plan with measurable targets for the next phase.		
Silver	Calculation	Formula = 100	Formula = ((45-40)/40)*100 = 11.96	Formula = 0
	Positive	• Execution and Electrical teams combine sound Lean awareness with effective use of LPS and Work Sampling.		

	Negative	• QA & QC, Design, and Plant & Machinery require additional training and coaching to close the gaps.		
Gold	Calculation	Formula = ((17-0)/40) * 100 = 43.44	Formula = 0	Formula = 0
	Positive	• Early Lean thinking is visible at the HVAC subcontractor, signalling potential supply-chain uptake		
	Negative	• A formal vendor strategy—clear incentives, onboarding training and Lean clauses in contracts—is still missing.		

Table 11 Project A ILMM Matrix

6.1.2 Discussion

The score pattern tells a clear story. Managers have invested clear effort in leadership visibility, basic 5S routines and a first round of Lean training. However, these practices have not yet reached the subcontractor interface or been supported by an integrated data platform.

Strengths

- **Housekeeping discipline.** Shadow boards, colour-coded aisles and red-tag zones reduced search time for tools and cut safety remarks by 22 percent.
- **Shorter slab cycles.** A simple value-stream map removed waiting and double-handling, reducing slab-pour time from 16 days to 6 days, a result consistent with international Lean benchmarks.
- **Growing Lean awareness.** Half the workforce has attended at least one Lean workshop, and daily briefings now include a “waste-of-the-day” example, building a common language for improvement.

Gaps

- **Reactive pull planning.** Look-ahead plans are prepared, but constraint logs are filled only after delays occur, limiting preventive action.
- **Subcontractor disengagement.** External crews rarely join daily huddles, so sequencing problems are discovered causing delay and rework rises.
- **Fragmented data.** Progress, safety and quality metrics live in separate Excel files; managers rely on verbal updates rather than a single dashboard.

Key actions

1. **Weekly Big-Room planning.** Mandatory attendance for vendor leads will give subcontractors early visibility of constraints and synchronise night-shift activities.
2. **Real-time PPC dashboard.** A simple mobile app will feed plan-versus-actual data directly to a shared screen, reducing manual Excel work.

3. **Lean-Essentials course for vendors.** A focused one-day session on pull planning and batch-size reduction will align subcontractor supervisors with site objectives.

6.1.3 Conclusion

Pilot A already demonstrates sound housekeeping and tangible cycle-time gains. By formalising collaborative planning and integrating vendor data, the project is likely to progress from Silver-Medium to Silver-High within the next reporting quarter.

6.2 Pilot B: 31-Storey Residential Tower

6.2.1 Results

This Mumbai tower (₹ 75 crore, 36 months) uses jump-form cores and post-tensioned slabs. Thirty respondents including engineers, BIM modellers, safety staff, subcontractor foremen and senior managers completed the survey.

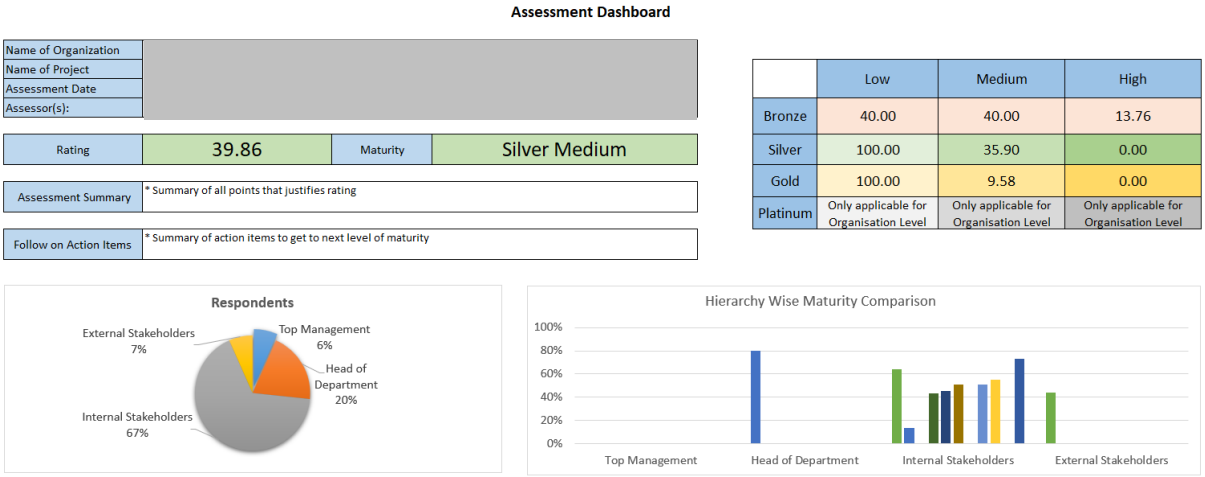

Figure 17 Project B Dashboard

The ILMM score of 39.86 falls in the upper Silver-Medium range as shown in Figure 17. The four broad categories, Top-Management, Head of Department, Internal stakeholder and External Stakeholder showed scores of 0%, 80%, 54% and 44% respectively on an average shown in the Figure 18 of radar chart. The variation is narrow ($\sigma = 0.6$), indicating a shared internal view. The detail score breakdown of the 4x3 matrix using the weighting approach defined in section 5.4 is shown in Table X with the reported positives and negatives for each level. The detail score breakdown of the 4x3 matrix using the weighting approach defined in section 5.4 is shown in Table 12 with the reported positives and negatives for each level.

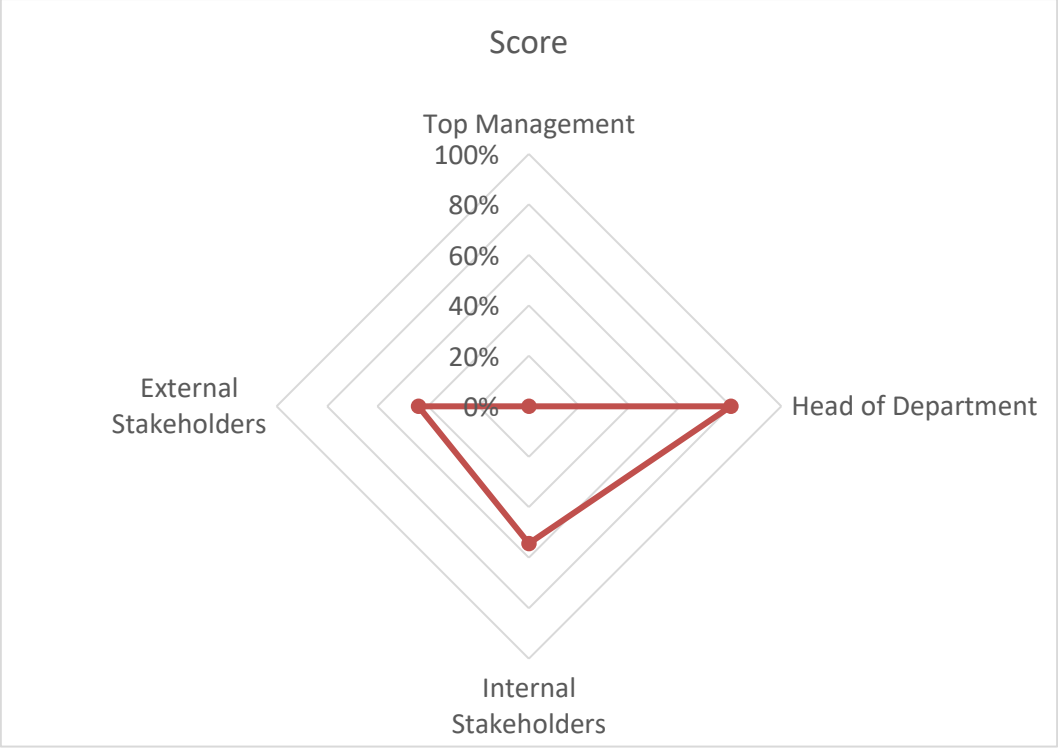

Figure 18 Project B Stakeholder Radar Chart

		Low	Medium	High
Bronze	Calculation	Formula = 60%*0+2*20%*100 = 40	Formula = (60%*0) + (20%*100) + (20%*100) = 40	Formula = (60%*0) + (20%*0) + (20%*((88-60)/40)*100) = 13.76
	Positive	• The Planning HoD and the site Lean Champion have deep Lean knowledge and drive day-to-day implementation.		
	Negative	• Top-management participation in the survey was absent, and HoD response rate was low. • Project-level Lean KPIs are not yet formalised, reducing long-term sustainment.		
Silver	Calculation	Formula = 100	Formula = ((54-40)/40)*100 = 35.90	Formula = 0
	Positive	• Internal stakeholders show strong Lean awareness and use technology to support LPS and Work Sampling.		
	Negative	• Budgeting & Finance staff have limited exposure to Lean concepts. • Tools such as VSM and a formal 5S sustainment system are not yet in place.		
Gold	Calculation	Formula = 100	Formula = ((44-40)/40)*100 = 9.58	Formula = 0
	Positive	• The main civil subcontractor participates in Lean meetings and exhibits basic Lean vocabulary.		
	Negative	• A comprehensive vendor-engagement plan—with incentives, penalties and clear Lean milestones—has not been defined.		

Table 12 Project B ILMM Matrix

6.2.2 Discussion

The numerical findings reflect a site that plans rigorously and uses digital tools effectively yet still struggles to extend Lean discipline to suppliers.

Strengths

- **Reliable Last Planner System.** Daily huddles and weekly look-ahead meetings sustain a Percent Plan Complete (PPC) of roughly 70 percent.
- **Advanced BIM workflows.** 4D sequencing has cut design RFIs by about a third, allowing smoother crane and jump-form scheduling.
- **Leadership integration.** Department heads carry Lean KPIs—PPC and 5S scores—into their monthly performance reviews, reinforcing accountability.

Gaps

- **Weak 5S on secondary areas.** Remote storage yards fail nearly half of random audits, undermining the otherwise strong site image.
- **No Lean clauses in subcontracts.** Without explicit KPIs, supplier performance ranges from excellent to poor.
- **Paper daily-progress reports (DPRs).** Manual entry causes 24-hour delays in updating the Lean dashboard, limiting prompt action.

Key actions

1. **Mobile 5S checklist.** A phone-based audit will cover all yards and post results openly, making neglect visible.
2. **Vendor-KPI addendum.** Simple targets—PPC above 70 percent and 5S above 80 percent—will be added to contract terms, with bonuses and penalties.
3. **Tablet DPR roll-out.** Finishing trades will pilot a tablet app that uploads progress, safety and quality data to the central dashboard.

6.2.6 Conclusion

The tower project achieved an upper Silver-Medium score on the strength of disciplined Last-Planner routines, 4D-BIM sequencing and proactive site execution team. Top management, however, did not submit questionnaires, leaving strategic intent unrecorded. Immediate next steps are to secure executive participation in the next ILMM cycle, embed Lean KPIs in subcontractor agreements and roll out mobile 5S and DPR apps. With senior endorsement and vendor alignment, the project can progress toward Silver-High or Gold maturity.

6.3 Pilot C: Industrial Greenfield Campus

6.3.1 Results

The greenfield campus (₹ 85 crore, 24 months) comprises three warehouses and an assembly block. Thirty-five people responded which comprised of internal staff, department heads, subcontractor leads and senior management.

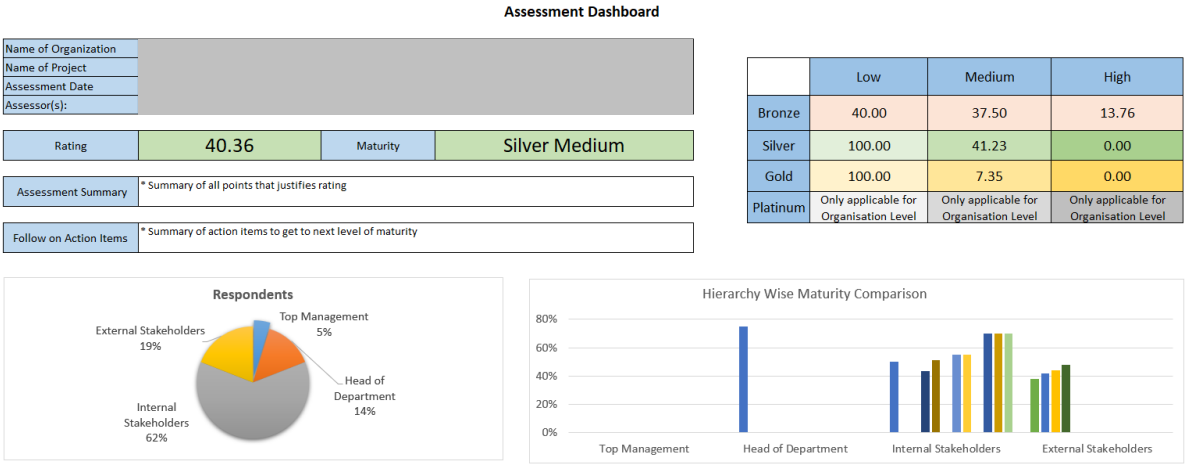

Figure 19 Project C Dashboard

The project scored 40.36, the highest in this study, nudging the Silver-Medium upper limit as shown in Figure 19. The four broad categories, Top-Management, Head of Department, Internal stakeholder and External Stakeholder showed scores of 0%, 80%, 56% and 43% respectively on an average shown in the Figure 20 of radar chart. In this project as compared to others there was more external participation going up to 19% out of the total respondents. The detail score breakdown of the 4x3 matrix using the weighting approach defined in section 5.4 is shown in Table 13 with the reported positives and negatives for each level.

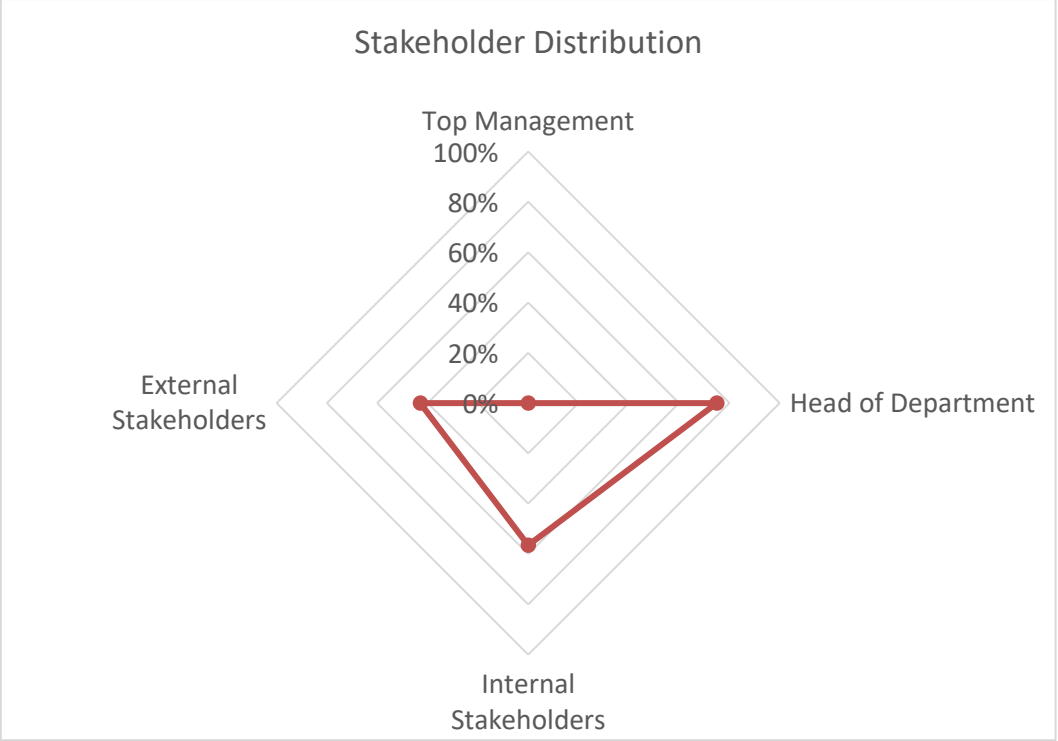

Figure 20 Project C Stakeholder Radar Chart

		Low	Medium	High
Bronze	Calculation	Formula = 60%*0+2*20%*100 = 40	Formula = (60%*0) + (20%*100) + (20%*100) = 40	Formula = (60%*0) + (20%*0) + (20%*((88-60)/40)*100) = 13.76
	Positive	• The Planning HoD and the site Lean Champion have deep Lean knowledge and drive day-to-day implementation.		
	Negative	• Top-management participation in the survey was absent, and HoD response rate was low. • Project-level Lean KPIs are not yet formalised, reducing long-term sustainment.		
Silver	Calculation	Formula = 100	Formula = ((56-40)/40)*100 = 41.23	Formula = 0
	Positive	• Most internal departments apply 5S, LPS and VSM with several processes are already being tech-enabled.		
	Negative	• The Design group lags on both technology adoption and Lean awareness.		
Gold	Calculation	Formula = 100	Formula = ((43-40)/40)*100 = 7.35	Formula = 0
	Positive	• Four major civil and PEB contractors are using Lean methods and relevant software tools.		
	Negative	• Policies, refresher training and standard Lean metrics are required to keep external teams on track.		

Table 13 Project C ILMM Matrix

6.3.2 Discussion

High planning discipline coexists with fragmented data systems and waning vendor support.

Strengths

- **Eight-week LPS cadence.** The team maintains PPC above 75 percent with daily constraint-removal huddles.
- **Mechanised logistics.** Automated stacker cranes reduce manual lifting hours by 40 percent, boosting both safety and speed.
- **Shared training.** A 12-module Lean certification course completed by staff and vendors has created a common improvement vocabulary.

Gaps

- **Data silos.** RFI logs, non-conformances and Lean metrics sit in separate software, preventing consolidated dashboards.
- **Static value-stream mapping.** The initial VSM has not been refreshed, so new bottlenecks remain hidden.
- **Vendor drift.** After initial training, subcontractor crews receive little coaching and slowly revert to old habits.

Key actions

1. **API bridge.** Connect RFI and NC data to the Lean dashboard so managers see all metrics in one place.
2. **Quarterly VSM workshops.** Refresh maps with cross-functional teams to reveal new waste and set new targets.
3. **Lean-coach pairing.** Assign each subcontractor a Lean coach for bi-weekly on-site reviews and quick problem-solving.

6.3.6 Conclusion

Project C led the sample with an upper Silver-Medium score, supported by eight-week pull planning, mechanised material handling and joint Lean certification. No responses were received from top management, creating a gap in leadership data. Advancing to Gold maturity will require executive engagement in the next assessment, integration of RFI/NC into dashboards and a formal coaching schedule for subcontractors. These steps will include governance in assessment and build the data rigour to sustain higher-level Lean performance.

6.4 Pilot D: Water Tunnel Infrastructure Project

6.4.1 Results

The final pilot is an 8.9-km hard-rock tunnel (₹ 120 crore, 42 months). Forty respondents include tunnel engineers, mechanics, QA/QC, safety staff and heads of department.

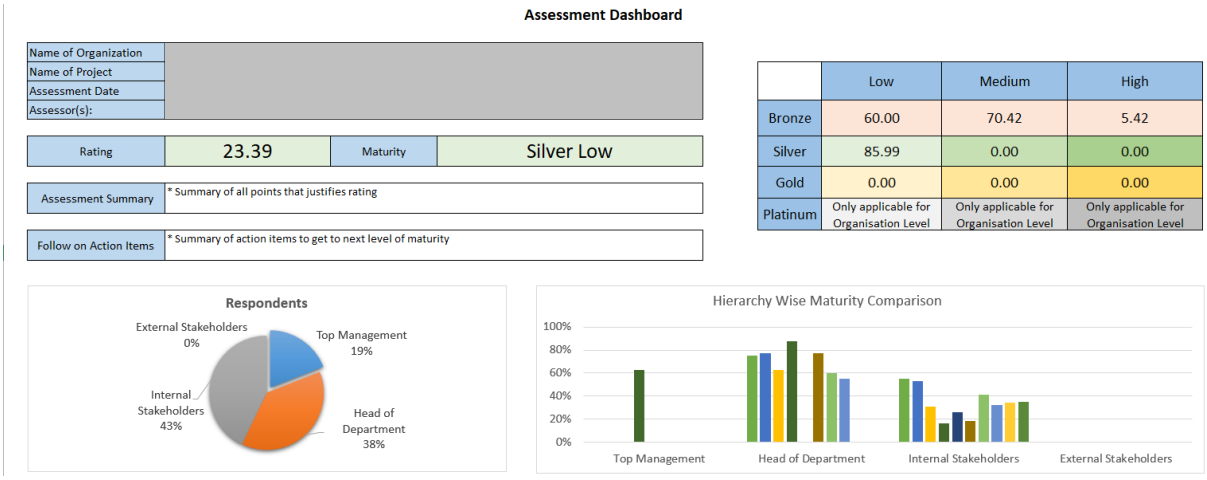

Figure 21 Project D Dashboard

The ILMM score of 23.4 places the project in Silver-Low as shown in Figure 21. The four broad categories, Top-Management, Head of Department, Internal stakeholder and External Stakeholder showed scores of 63%, 73%, 34% and 0% respectively on an average as shown in the Figure 22 of radar chart. Score variance is widest ($\sigma = 0.8$), and no vendor responses were captured. The detail score breakdown of the 4x3 matrix using the weighting approach defined in section 5.4 is shown in Table 14 with the reported positives and negatives for each level.

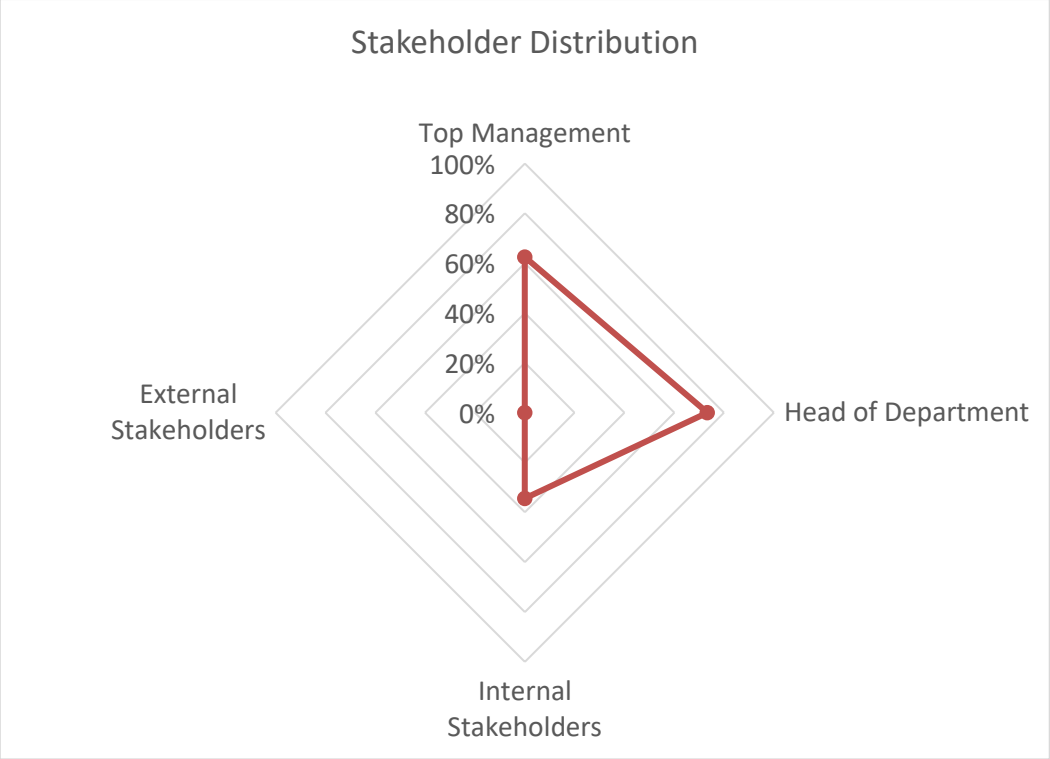

Figure 22 Project D Stakeholder Radar Chart

		Low	Medium	High
Bronze	Calculation	Formula = (60%*100) + (2*20%*100) = 100	Formula = (60%*((63-40)/40)*100) + (20%*((73-40)40)*100) + (20%*100) = 70.42	Formula = (60%*0) + (20%*0) + (20%*((71-60)/40)*100) = 5.42
	Positive	• Top management and HoDs—especially QA & QC and Planning—show strong Lean awareness. • Lean Champions have initiated several enhancement projects.		
	Negative	• A long-term strategy is needed to maintain the early momentum and embed Lean in daily routines.		
Silver	Calculation	Formula = ((34-0)/40)*100 = 85	Formula = 0	Formula = 0
	Positive	• Planning and Survey departments combine Lean tools with robust digital reporting.		
	Negative	• QA & QC still lack familiarity with basic Lean terminology and practices, limiting cross-department balance.		
Gold	Calculation	Formula = 0	Formula = 0	Formula = 0
	Positive	• No external stakeholders are yet part of the Lean programme.		
	Negative	• Key suppliers and specialist subcontractors must be integrated into the Lean framework before higher maturity can be claimed.		

Table 14 Project D ILMM Matrix

6.4.2 Discussion

Basic Lean ideas are supported by senior leaders yet remain siloed at the working face, and manual records delay feedback.

Strengths

- **Visible leadership.** Directors join weekly Gemba walks, signalling priority and removing high-impact barriers.
- **Safety-driven 5S.** Daily audits at the tunnel face reduced trip incidents by 22 percent.
- **Kaizen engagement.** Sixty percent of crew participated in short Kaizen events that produced colour-coded hose reels and improved air-line routing.

Gaps

- **No Big-Room planning.** Engineering, procurement and vendors plan in isolation, causing TBM stoppages.
- **Supplier detachment.** Equipment OEMs rarely attend planning and do not share performance metrics.
- **Paper logs.** Safety and progress data are handwritten and keyed into SAP two days later, muting real-time decisions.

Key actions

1. **Weekly Big-Room sessions** that include OEM representatives and align tunnel sequencing with supply schedules.
2. **Vendor KPIs** (uptime, response time) embedded in review cycles to create shared accountability.
3. **Mobile safety/progress app** piloted with one tunnel crew, uploading data directly into SAP.

6.4.6 Conclusion

Leadership commitment and daily 5S routines give the tunnel a sound base, but the project remains in the Silver-Low band. Because pull planning is informal and suppliers stay outside the conversation with hand-offs still being managed in silos. The immediate step is to launch a structured Last Planner System with weekly Big-Room meetings that include equipment vendors and shotcrete crews. Coupled with a program for building lean awareness among external stakeholders, these changes should lift the project into Silver-Medium maturity.

6.5 Discussion

Across the four pilot's certain patterns are clear. First, basic Lean awarness is achievable in most Indian settings without advanced tools. All projects recorded strong scores for 5S routines, daily safety walks and visible leadership involvement. These early wins suggest that site order and management presence provide a dependable foundation for further Lean work.

The projects begin to diverge when deeper workflow practices are assessed. The two building projects—the residential tower and the green-field campus—performed better in the Process and Methods & Tools dimensions. Their repetitive floor cycles synced well with the Last Planner System and with 4D BIM for clash detection and sequencing. In contrast, the railway-station upgrade and the hard-rock tunnel found it difficult to keep pull plans current because of variability in work fronts and restricted access. This indicates that infrastructure projects may need a more collaborative approach and shorter feedback loops to achieve similar gains seen in other projects which adopted Last Planner System.

A common observation across projects was that support departments like Store, QA & QC, Survey, EHS, Design, and Plant & Machinery showed lesser Lean understanding and slower uptake, despite marked progress in the other major Internal Departments. Supplier involvement is another dividing line. Internal teams on every site improved faster than their subcontractors. As internal maturity approached the upper Silver band, gaps in vendor participation became the main barrier to further progress. Vendors often missed planning meetings, and their contracts rarely carried Lean key-performance indicators, limiting their incentive to adopt new routines.

Technology uptake followed the same gradient. Projects with reliable pull-planning habits were already piloting dashboards and mobile apps, while the tunnel project, still paper-based, remained in Silver-Low. This suggests that Lean tools and simultaneous technology adoption delivers higher value and helps sustain Lean behaviour and principles.

Finally, the role of Lean Champions changed with maturity. On lower-scoring sites champions acted as evangelists, explaining basic terms and arranging first trials. On higher-scoring jobs they served as coaches, refining existing routines and mentoring vendors. This shift from evangelism to coaching is a practical signal that Lean thinking is moving from an individual initiative to a shared organisational habit.

Chapter 7 Conclusions and Future Scope

7.1 Conclusions

This thesis set out to develop and validate a Lean-maturity assessment tool tailored for the unique needs of Indian construction projects. By combining rigorous literature analysis, practitioner input and hands-on field trials, the study delivers both a refined diagnostic instrument and clear guidance on how to use its results to drive real improvement.

Key outcomes of the study

1. **Gap diagnosis** – A systematic literature review and expert panels identified five barriers that prevent existing Lean-maturity tools from working well on Indian sites: lengthy surveys, unfamiliar terminology, heavy data demands, unbalanced dimension weights, and neglect of owner–contractor dynamics.

2. **Context-sensitive model design** – To answer those gaps, the study configured the Indian Lean Maturity Model (ILMM) around five project-relevant dimensions, a 27-item question set, a five-point Likert scale, an interval-plus-Delphi weighting method and automated radar dashboards.

3. **Repeatable six-step workflow** – A clear sequence—initiation, data collection, scoring, weighting, visualization and feedback—was established and built first in Excel, then in a scalable web platform, ensuring both offline usability and cloud storage for audit trails.

4. **Pilot validation on four projects** – Applying the ILMM to a station upgrade, a residential tower, a green-field campus and an infrastructure tunnel produced composite scores from Silver-Low 23.4 to upper Silver-Medium 40.4 and delivered role-segmented dashboards within one week of data capture.

5. **Actionable improvement plans** – Dashboards translated the findings into concrete next steps such as Big-Room planning, standard KPI boards, vendor mentoring and mobile progress apps, giving each site a practical roadmap toward higher maturity.

Thus, this study demonstrates that a lightweight, yet data-rich assessment tool can benchmark Lean capability in Indian construction with numerical accuracy, expose stakeholder-specific

priorities and supply an actionable roadmap for continuous improvement. Because the ILMM combines simplicity, scalability and clear visual feedback, it is well suited for both industry deployment and further academic exploration of Lean transformation in the Indian context.

7.2 Future Scope

The ILMM tool can be made even more practical by improving how offline and online work are connected. In future versions, assessors should be able to complete the questionnaire in the Web platform when they have no internet and then simply sync their data when they return to connectivity. This change would remove any disruption caused by poor site networks and ensure all responses end up in the central database without extra effort.

Different users need different views of the same data. By adding role-based dashboards, senior managers could see high-level trends and overall maturity scores, department heads could focus on their own team's performance, and site crews could view only the immediate action items and visual boards they need. Such tailored interfaces would reduce information overload and help each group act on the results that matter most to them.

Exporting findings into familiar formats would further streamline the follow-up work. A one-click report export—automatically generating a PowerPoint slide deck or Word summary using prebuilt templates—would save assessors time and ensure consistent presentation of results and recommendations. Alongside this, version control for the questionnaire itself would allow the tool to evolve over time: each new set of questions or revised wording would be tagged with a version number so that past assessments remain directly comparable.

Finally, the ILMM can expand its Lean-method coverage by including a handful of simple, widely used practices in India. Adding questions on Choosing by Advantage and Lean in Design would record whether teams have documented the best way to perform routine tasks. Including the 5 Whys technique would show whether crews use a basic root-cause analysis to solve problems. And tracking Kaizen events would highlight short, focused workshops that drive rapid improvements. By embedding these common methods into the assessment, the tool will capture more of the day-to-day Lean activity on sites and give a fuller picture of how teams are learning and improving.

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Appendix A – Questionnaire

Category Wise Question Set

Category 1 : Top Management

1. What is your understanding of Lean?
2. What is your understanding of value and Waste?
3. What do you feel is the difference between Project delivery using Lean principles and Conventional Project Management principles?
4. What benefits do you anticipate by adopting Lean Construction?
5. What kind of Lean Awareness training have you taken?
6. Document proof of Lean Strategy Document.

Category 2 : Head Of Department

1. What is your understanding of Lean?
2. What is your understanding of value and Waste?
3. What do you feel is the difference between Project delivery using Lean principles and Conventional Project Management principles?
4. What benefits do you anticipate by adopting Lean Construction?
5. What kind of Lean Awareness training have you taken?
6. Document proof of Department Level Lean Strategy Document.

Category 3 : Lean Awareness

1. What is your understanding of Lean?
2. What is your understanding of value and Waste?
3. What do you feel is the difference between Project delivery using Lean principles and Conventional Project Management principles?
4. What benefits do you anticipate by adopting Lean Construction?
5. What kind of Lean Awareness training have you taken?
6. Document proof of Training certificate.

Category 4 : Last Planner System

1. Do you practice LPS at site? If no, skip the rest of the section.
2. Has your team undergone LPS training?
3. Do you have Big Room?
4. Is LPS practiced for the entire project or only critical facilities?

5. Do you have Phase Schedule? Please submit the same during assessment

6. Do you have weekly Look Ahead Plan? If yes, Submit LAP and Constraint Log for last three weeks.

7. Do you prepare weekly work plans? If yes, submit WWP for last three weeks

8. Do you have daily standup meeting? What time is the stand up huddle done?

9. Submit PPC data and graph for the Project.

10. When are weekly planning meetings done? Who participates in those? Submit list with name, role/designation, organization

11. Do you use 5 why to collect delay reasons? Submit delay reasons for the project

12. What steps have you taken to increase PPC and mitigate top delay reasons? If yes, provide proof for the interventions done and results of the same

Category 5 : Value Stream Mapping

1. Have you done any VSM analysis at the site? If no, skip the rest of the section

2. Have site personnel and supervisors undergone VSM training?

3. What processes were considered for VSM? Why were they chosen? Provide a list of all VSMs done on site

4. Do you have Current State Value Stream Map? If yes, submit the same as a document.

5. Do you have Future State Map? If yes, submit the same as a document and describe the interventions planned.

6. What are the statistics on Process Times (PT) and lead Times (LT)?

7. What Interventions did you take to improve them? Provide relevant documents for the same.

8. What stakeholders and resources were considered?

9. What was the timeframe considered and expected results?

10. Was the VSM intervention successful? What quantifiable benefit was gotten through VSM?

11. Do you plan to do more VSM?

Category 6: 5S

1. Have you implemented 5S on your site? If no, skip the rest of the section

2. What areas have you considered for 5S? Provide a list of all areas where 5S is being considered

3. Have site personnel and supervisors undergone 5S training?

4. Do you have dedicated routine/practice to implement 5S?

5. Do you have proper awarness boards in Site?
6. How often %s audits are done? Provide the evidence for last 5 audits.
7. Do you have Red Tag Area?
8. Do you follow "Place for everything and everything at its place" approach?
9. What quantifiable benefit was gotten through 5S?
10. Was the 5S intervention helpful? Do you plan to roll out more 5S?

Category 7: Work Sampling

1. Have you done Work Sampling on your site? If no, skip the rest of the section
2. Have site personnel and supervisors undergone tour and crew based Work Sampling training?
3. What kind of Work Sampling have you done? Crew or Tour? Provide document of data for the same
4. What categories have you considered and defined as VA, NAVN. NVA?
5. What frequency do you do sampling?
6. What interventions have you taken to improve site situation? Provide documents for the same
7. What time period was considered?
8. What were the expected the results?
9. What quantifiable benefit was gotten through Work Sampling?
10. Was the work sampling intervention helpful? Do you plan to do more in other locations?

Category 8 : Technology

1. Have you done any digitization of the project from design to procurement to planning and execution? If no, skip this section
2. Which Processes have you Digitalized? Please provide a list and the technology used against each of them
3. What tool do you use for Planning? How are plans created and shared, both internally and externally? Is the solution cloud based on desktop based?
4. What tool do you use for Design? How are design drawings created and shared, both internally and externally? Is the solution cloud based on desktop based?
5. Do you create 3D models? If so, what tool do you use for BIM? How are BIM models created and shared, both internally and externally? Is the solution cloud based on desktop based?

6. What tool do you use for Collaboration? How is information including documents shared, both internally and externally
7. What tool do you use to manage procurement and materials receipt and shipment at the Stores?
8. What tool do you use for Project Monitoring? How is daily progress captured? How is it shared? How is it used for re-planning?
9. What tool do you use for Accounting & Finance? Is it desktop based on cloud based?
10. What tool do you use for Quality and Safety? Is it desktop based, web based, or mobile based?
11. What quantifiable benefit was gotten through technology and digitization?
12. Was the technology and digitization intervention helpful? What is the technology roadmap and plans for the project?

Category 9 : Operational Targets

1. What operational targets were taken up for intervention and improvement? If no, skip this section
2. What is the Process?
3. Which lean tools used?
4. What was the Technology Intervention?
5. Wat were the Expected Benefits? Were the benefits realized?
6. What was the planned timeframe for Implementation?
7. Who were the impacted Stakeholders (list both internal and external)?
8. What other operational targets are being planned for intervention, both internal and external

Category 10 : Lean Champions

1. What is/are your roles/ shared roles?
2. What % of time (in a week) you spend in driving Lean?
3. What do you feel is the difference between Project delivery using Lean principles and Conventional Project Management principles?
4. Where are you doing an awareness?
5. How are you doing an awareness?
6. How do you drive collaboration and lean culture?

Appendix B – Tool Development Document

Project Overview

The Indian Lean Maturity Model Assessment Tool was developed as a comprehensive web-based platform enabling efficient assessment of lean maturity across organizational departments. The system features dual interfaces for Assessors and Respondents, creating a structured workflow from assessment creation through submission and evaluation.

Requirements Analysis & Design

To start with a detail requirement prompt was developed with the help ChatGPT clearly specific the flow of assessment, pages involved, and the type of output required (Given in Annexure). This was then given to Claude after which development began with thorough analysis of the comprehensive requirements document specifying a 10-page application flow.

The design phase established a system architecture featuring:

- MongoDB document database for flexible data storage
- Node.js/Express backend providing RESTful API services
- React frontend delivering an intuitive user interface
- Tailwind CSS for responsive styling without custom CSS

The data model was carefully designed to handle complex relationships between assessors, projects, respondents, categories, questions, and assessment scores.

Implementation Process

Development followed a systematic approach:

1. Backend Foundation: Created MongoDB schema models and Express routes with proper validation
2. Database Seeding: Implemented scripts to parse question categories and seed assessor data
3. Frontend Framework: Established React application with routing and authentication context
4. User Interfaces: Developed specialized interfaces for:
   - Assessors: project management, CSV upload, category mapping, and assessment scoring
   - Respondents: multi-project selection, questionnaire navigation, and submission

Technical Challenges & Solutions

Throughout development, several technical challenges were addressed:

- Database Connectivity: Resolved connection issues by implementing explicit database naming

- Import Path Management: Fixed React component import paths for proper module resolution
- CSV Processing: Created robust parsing with proper error handling for respondent data
- Category Mapping: Developed dynamic mapping interface between departments/levels and categories
- Level Format Compatibility: Implemented flexible level format handling (with/without "L" prefix)
- Multi-Project Support: Added functionality for respondents associated with multiple assessments
- Assessment Scoring: Fixed project ID reference issues in the assessment scoring process

Testing & Refinement

The application underwent iterative testing focusing on:
- Email validation and role-based access control
- CSV upload and processing
- Category mapping functionality
- Respondent assessment flow
- Scoring and feedback mechanisms

Each component was debugged and refined to ensure robust operation and proper data handling.

Final Deliverable

The completed application delivers a fully functional assessment system with:
- Secure role-based access for assessors and respondents
- Intuitive project management for assessors
- Simplified assessment experience for respondents
- Comprehensive scoring and feedback capabilities
- Simple interactive Summary for generating score insights
- Modular architecture allowing future enhancements

The ILCE Lean Maturity Model Assessment Tool successfully fulfils all requirements while providing a scalable platform for organizational lean maturity assessment.

Areas for Future Enhancement

1. **User Roles & Permissions:**
    i. Implement robust authentication (e.g., passwords, SSO) instead of just email validation.

ii. Introduce fine-grained role-based access control (RBAC) for different user types (e.g., Super Admin, Project Admin, Assessor).
iii. Support multiple Assessors contributing to a single project assessment.
iv. Refine visibility settings for different user types within a cloud-based platform.

2. **Assessment Content & Workflow:**
   i. Add functionality for Assessors to add, edit, or manage category-specific questions post-initial setup.
   ii. Implement a mechanism to lock respondent answers after scoring is completed by the Assessor.
   iii. Allow respondents to save assessment progress partially and resume later.
   iv. Introduce version control for assessment categories and questions.
3. **Project & Data Management:**
   i. Enable editing of core project setup details (like name, scope) even after initial publication, potentially with versioning or audit trails.
   ii. Enhance CSV upload validation to catch invalid email formats or non-existent respondent/assessor emails during the upload phase.
   iii. Improve error handling during CSV processing to provide clearer feedback on failed rows.
4. **Reporting & Analytics:**
   i. Enhance Spider and Bar charts to aggregate and compare data across multiple respondents, departments, levels within a project, or even across different projects within an organization.
   ii. Allow customization of the number of respondents displayed in comparison bar graphs.
   iii. Implement more detailed drill-down dashboards for deeper analysis of assessment results.
   iv. Integrate AI tools (e.g., Large Language Models) to automatically summarize qualitative feedback (positives/negatives) provided by assessors.
   v. Add data export functionality (e.g., CSV, Excel) for summary and raw assessment data.
5. **UI/UX:**
   i. Develop a more professional and consistent user interface, potentially aligning with other ILCE platform styles.

ii. Improve user feedback mechanisms for actions like saving, submitting, and potential errors.
iii. Enhance the map component with features like searching or better handling of numerous project markers.

6. **Technical & Architectural Improvements:**
   i. Strengthen server-side input validation across all API endpoints.
   ii. Refactor backend code (currently mostly in app.js) into a more modular structure (e.g., controllers, services).
   iii. Optimize database queries and ensure appropriate indexing for scalability.
   iv. Manage configuration (like database connection strings) using environment variables instead of hardcoding.
   v. Regularly update frontend and backend dependencies and address any security vulnerabilities.
   vi. Standardize data formats (e.g., the respondent 'Level' format).
   vii. Improve backend error logging for easier debugging.
7. **Deployment & Infrastructure:**
   i. Identify and migrate to a suitable cloud-based platform (e.g., AWS, Azure, GCP) for better scalability, reliability, and management.
   ii. Implement proper CI/CD pipelines for automated testing and deployment.

PROMPT TO LLM

I want a full-stack implementation (front-end & back-end) of an "Indian Lean Maturity Model Assessment Tool by ILCE," incorporating the detailed specifications below. Please provide the code or a thorough technical specification, including real, working data models, endpoints, and sample logic.

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1. OVERVIEW

Website Purpose

- Enable an **Assessor** to create/manage Lean Maturity Model assessments for multiple **Respondents**.
- Let **Respondents** log in by email, fill category-based questions, and submit them.
- Let **Assessors** score the responses and give feedback.

Primary Data Sources

1. **Internal Assessor Email Data**:

- All valid Assessor emails are **seeded** into the backend (e.g., database).
- No CSV upload is needed for Assessors.

2. **CSV Upload**:
    - For Respondents **only**, containing fields such as **Email, Department, Level**, etc.
3. **TXT File**:
    - Contains the **category-based question sets**.
    - Each category has a set of questions.

Key Change

- **Page 2** validates the email address. If it matches an **Assessor email** (already in the backend), proceed to Assessor flow. If it's in the **CSV** for a given project (Respondent data), proceed to Respondent flow. Otherwise, show an error.

---

2. PAGE-BY-PAGE STRUCTURE & FLOW

1. **Page 1: Landing Page**
    - Title: "Indian Lean Maturity Model Assessment Tool by ILCE"
    - Two clickable buttons: **Accessor** and **Respondent**
    - Clicking "Assessor" or "Respondent" → Navigates to **Page 2** (Email Input & Validation).
2. **Page 2: Email Input & Validation**
    - Single field to enter **Email**.
    - Backend checks if email is in the **Assessor** table/list → If yes, proceed to **Page 5** flow.
    - Else, check if email matches a **Respondent** in the CSV data for an existing project → If yes, proceed to **Page 3** flow.
    - Else, show error (invalid user).
3. **Page 3: Answer Input (Respondent only)**
    - Respondent sees **only** the question categories assigned to their **Department + Level** (defined by the CSV and the Category Mapping in Page 7).
    - Each category is a separate sub-page/tab with a **Next** button to move through categories.
    - Question data pulled from the **TXT file**.
    - Respondent enters answers (up to 1500 characters each).
4. **Page 4: Acknowledgment & Submit (Respondent)**

- Respondent reviews all answers.
- Provides a digital signature or checkbox.
- On "Submit," system stores responses in the database.

5. **Page 5: Selection Page (Assessor only)**
    - Two buttons:
        - **Create** → goes to **Page 6**
        - **Assessment** → goes to **Page 8**
6. **Page 6: Create Project (Assessor)**
    - Fields:

1. Organization Name
2. Project Name
3. Contract Type
4. Total Scope
5. Project Value

- Option to **upload Respondent CSV**, which includes Email, Department, Level, etc.
- After upload, system associates each row with this project's details.

2. **Page 7: Category Mapping Page (Assessor)**
    - Assessor sets which categories (from the TXT file) apply to specific combinations of **Department** and **Level**.
    - Example: "Category 1, 4, 7" apply to Department "Engineering" at Level "L3," etc.
    - This mapping determines which questions a Respondent sees on Page 3.
    - Once completed, Assessor **publishes** the assessment so Respondents can access it.
3. **Page 8: Selecting Project for Assessment (Assessor)**
    - Assessor picks from a dropdown of previously created projects.
    - Proceeds to Page 9 to view and score Respondent data.
4. **Page 9: Selecting Respondent for Scoring (Assessor)**
    - Displays all Respondents (from the chosen project) who have completed their questions.
    - Assessor clicks on a Respondent's name → goes to Page 10 to view/score their answers.
5. **Page 10: Assessment Page (Scoring)**

- Shows each category question and the Respondent's answer in read-only form.

- Allows the Assessor to assign an **integer score (0–4)** to each question.
- Each category has two free-text boxes at the bottom for "Positives" and "Negatives."
- Scores and feedback are saved, then the Assessor can move on to the next Respondent.

---

3. REQUIRED FUNCTIONALITY

1. **User Management & Login**
    - **Assessor**: Email addresses **preloaded** in the backend DB.
    - **Respondent**: Validated from CSV data.
    - **No** typical "username/password" registration is needed—just email-based validation.
2. **Data Storage / Models**
    - **Assessor Model**:
        - id, email, name (optional), etc. (seeded initially)
    - **Project Model**:
        - id, organizationName, projectName, contractType, totalScope, projectValue, plus metadata.
    - **Respondent Model**:
        - id, email, department, level, projectId, etc.
    - **Category Model** (or a direct reference to the question sets in the TXT file).
    - **Question Model**:
        - If storing questions in DB, each question belongs to a category.
    - **Answer Model**:
        - id, respondentId, projectId, questionId, answerText.
    - **Score/Feedback Model**:
        - id, assessorId, respondentId, questionId, score (0–4), plus positives & negatives per category.
3. **CSV Upload**
    - For the **Respondent** data only.
    - Includes (at minimum) **Email, Department, Level** columns.
    - Tied to a specific project upon upload.
4. **Category Mapping**
    - On Page 7, an Assessor sets which categories go to which **Department + Level** combos.

- The site references this map to show categories on Page 3 for that particular Respondent.

5. **Question Sets**
    - Provided in a **TXT file** (sample included).
    - Each category has multiple questions, each with a 1500-character response limit.
    - A solution might parse and store them in the DB or maintain them as a reference.
    - **Example Categories**: Top Management, Head of Department, Lean Awareness, Last Planner System, etc.
6. **Scoring**
    - Once the Respondent submits (Page 4), the Assessor can see these answers and assign a **0–4** score per question.
    - Each category includes **Positives** and **Negatives** text fields.

---

4. SAMPLE TECHNOLOGY STACK & REQUIREMENTS

- **Front-End**:
    - React, Vue, or Angular (or just HTML/CSS/JS if simpler).
    - Must implement the multi-page flow with routing.
- **Back-End**:
    - Node.js/Express (or Python Django/Flask, or .NET)
    - Must handle the CSV parse/upload logic and store the data.
    - Endpoint structure (e.g., /auth/validateEmail, /project/create, /project/uploadCsv, /category/map, /assessment/score, etc.).
- **Database**:
    - MySQL / PostgreSQL / MongoDB (or any relational or NoSQL store).
    - Must have clear data models for **Assessors**, **Projects**, **Respondents**, **Categories**, **Questions**, **Answers**, and **Scores/Feedback**.

---

5. OUTPUT REQUEST

Please produce a Full-Stack Solution with:

1. **Front-End Code**
    - Sample or detailed React/Vue/Angular components, routing approach, forms for each page (1–10).

- How to handle Next/Submit flows.

2. **Back-End Code**
    - Models/Schemas.
    - API routes and logic (Node/Express, Python, or your chosen framework).
    - CSV upload endpoint, category mapping endpoint, answer submission endpoint, scoring endpoint, etc.
    - Database interaction for create/read/update.
3. **How to Seed Assessor Emails**
    - Seeding script or DB seed for Assessor table so that Page 2 knows which emails are valid for Assessors.
4. **Data Model Diagrams**
    - Explanation or ERD of how the tables/collections relate (Project → Respondents, Category → Questions, etc.).
5. **Validation & Error Handling**
    - For email input on Page 2, CSV upload checks, question answer length, etc.
6. **Deployment Instructions**
    - Summaries of how to run migrations, seed data, and build the front-end.

Ensure:

- The solution addresses the 10-page flow exactly.
- Assessor and Respondent usage is clearly separated by email.
- CSV is only for Respondents. Assessor emails come from the seeded table.
- Use the attached "Category Wise Question Set.txt" to demonstrate how categories and questions might be stored or parsed.

Second Prompt

I have an existing Lean Maturity Model Assessment Tool (with 10 pages) that is already functioning based on your previous code/technical specification. Now, I want to add the following features and changes:

1. Add a New "Summary Page" (Page 10 → renamed to Page 11, or just call it Page 10 if you prefer)

1. **Purpose**:
    - Display scores for each Respondent in a visually appealing manner.
    - Compare Respondent scores by project and organization.
2. **UI Requirements**:

- Include **spider/radar charts** and other interactive charts (bar, pie, or line as needed) to visualize:
    - **Category-wise scores**
    - **Overall Respondent scores**
    - **Comparisons** of Respondents within the same project
- Summaries or tables of raw data (e.g., category scores, total scores, etc.).

2. Make the Existing UI More Interactive

1. For the **new summary visuals**, please:
    - Retrieve **scores** and **weightages** from the database.
    - Calculate the aggregated scores (explained in the next sections).
    - Plot them in dynamic charts (preferably a **radar/spider chart** to show multi-category performance).
2. Provide options to filter results by **Project**, **Department**, **Level**, or **Respondent**.

3. Changes in the "Category Mapping" Page (Originally Page 7)

1. **Weightage Assignment**:
    - **Assessor** can now assign a weightage to each **Category** for a given **Level + Department** combination.
    - **Mandatory Check #1**: For any particular **Level + Department** combination, the sum of **all category weightages must** be **100**.
    - **Default Setting**: If the Assessor does not manually change weightages, **all categories** should have **equal weightage** (evenly split so that their sum is 100).

4. Changes in the "Assessment" Page (Originally Page 10)

1. **Per-Question Weightage**:
    - By default, each question within a category has an **equal weightage**.
    - The **Assessor** should be able to **change** these weightages.
    - **Mandatory Check #2**: For all questions within a category, the **sum of the weightages** must be **100** at the time of submission.

5. Score Calculation

We need to update how category-level and overall (respondent-level) scores are calculated, considering category weightages **and** question-level weightages.

1. **Category Score**
    - Formula is the **sum product** of question points × question weightages (converted to a fraction).

- **Example**: Category with 6 questions and the following data:

Question	Points	Weightage
Q1	3	10%
Q2	2	15%
Q3	4	20%
Q4	3	10%
Q5	1	25%
Q6	2	20%

- **Aggregate category score** = (3×10%) + (2×15%) + (4×20%) + (3×10%) + (1×25%) + (2×20%) = **2.35**

2. **Overall Respondent Score**
    - Once each category has an **aggregate category score**, we again apply a **sum product** with the **category weightage** (assigned in Page 7).
    - If a Respondent has categories A, B, C, with scores SA, SB, SC, and weightages WA, WB, WC (that sum to 100), then:
      Respondent's Overall Score = (SA × WA%) + (SB × WB%) + (SC × WC%)
    - Example: If Category A's score is 2.35 (weightage 30%), Category B's score is 3.2 (weightage 50%), Category C's score is 1.8 (weightage 20%), the total = (2.35×0.30) + (3.2×0.50) + (1.8×0.20).

6. Implementation Notes

1. **Data Model Updates**:
    - **Category-level weightage**: Store in a new field in the DB (e.g., CategoryAssignment model) with columns for department, level, categoryId, and weightage.
    - **Question-level weightage**: Store in the existing or new model (e.g., QuestionAssignment or in the scoring table). Each row might have questionId, respondentId (or project?), and weightage.
2. **Frontend Forms**:
    - On Page 7 (Category Mapping), add a **weightage input** for each category. Validate the total = 100.
    - On Page 10 (Assessment Page), add a **weightage input** for each question in the category. Validate the total = 100.
3. **Default Values**:

- Category-level default → even distribution summing to 100.
- Question-level default → even distribution summing to 100.

4. **Scoring & Storage**:
    - After the **Assessor** inputs or updates weightages, store them.
    - Use these weightages + Respondent's assigned points to dynamically compute **aggregate** category scores and overall scores.
5. **Summary Page (Page 10 or Page 11)**:
    - Provide a route and UI that:
        - Pulls all final scores from DB.
        - Calculates or displays final aggregated scores.
        - Visualizes them with spider/radar charts or any other charts.
        - Allows filtering by **Project**, **Respondent**, etc.

7. Output Requested

Please update the existing code you provided so that it includes:

1. **New forms** and **DB fields** for category-level weightage and question-level weightage.
2. **Validations** ensuring both sets of weightages always sum to 100.
3. **Revised scoring logic** that computes category and overall scores based on the assigned weightages.
4. **New summary (Page 10)** that includes interactive charting (spider/radar graphs) to compare Respondent scores.
5. Any **database migrations** or new scripts needed to add weightage columns/tables.
6. **Sample or demonstration** of how a user can assign weightages, fill out a score, and see the resulting spider chart.