

Smart Technologies for the Modernization of Ready-Mix Concrete Operation

Ankush Patel^{1*}, J.R. Pitroda², Jagruti P. Shah³, Jignesh Suthar⁴

Abstract

Ready-mix concrete is a product that is ready to use. It is made up of cement, sand, aggregate, and water. In accordance with client requirements, a transit mixer transports the combined material to the location. Ten years ago, ready-mix concrete was first introduced to the Indian construction industry; however, its high tax rates and excessive costs initially hindered its widespread use. However, it became more popular because it required less strength, time, and effort than site-mixed concrete. Because of its closed chamber mixing method, ready-mix concrete is also environmentally favorable since it lowers air pollution and noise. For big or medium-sized projects, ready-mix concrete has been shown to be a time and cost-effective solution, despite early resistance.

Keywords: Concrete, ready-mix concrete, transportation, product efficiency, cement, sand, aggregate

INTRODUCTION

Concrete mixed in a fixed mixer in a main batching and mixing plant or in a truck-mixer and distributed in fresh form to the buyer either at the site or into the buyer's vehicles, according to Indian Standard Specification IS 4926:2003. A specified mixture of cement, sand, aggregates, and water makes up ready-mix concrete (RMC), a substance that is ready to use. RMC is a form of concrete that is produced in a central batching facility using a predetermined recipe or the customer's requirements.

The majority of RMC is produced using computer-controlled processes and is delivered to construction sites using advanced tools and techniques. It is transported to a job site, frequently in truck mixers that may mix the concrete's ingredients while traveling or right before the batch is delivered.

Concrete may be pumped up to 80 meters with a boom placer.

Typically, orders for RMC are placed in cubic yards or meters. In India, the RMC industry is still in its early stages. In contrast to wealthy nations, where RMC makes up approximately 70% of cement usage, RMC makes up less than 5% of cement usage in India. According to industry people taking part, RMC's share of cement manufacturing will rise from the present level of around 5% to the global average of 70%.

TYPES OF RMC

RMC is available in three types, based on how the materials are mixed, as explained below.

- Transit-mixed concrete.
- Shrink-mixed concrete.
- Central-mixed concrete.

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Transit-Mixed Concrete

Dry-batched concrete is when all the materials, including water, are put straight into the truck mixer. The drum spins fast at first to mix everything well, then turns slowly to keep the mix ready. There are three types of this kind of concrete.

- *Concrete mixed at job site:* During transit, the drum rotates slowly at about 4 rpm, then mixes at 12–15 rpm for 70–100 revolutions before discharge at the site.
- *Concrete mixed in transit:* During transit, the drum rotates at around 8 rpm for 70 spins, then slows to 2 rpm for agitation until the concrete is discharged.
- *Concrete mixed in the yard:* In the yard, the drum rotates at 12–15 rpm for about 50 revolutions, then the concrete is gently stirred during transportation.

Shrink-Mixed Concrete

After partial mixing in the plant mixer, final mixing is done during transit in a truck-mounted drum; the need for drum mixing depends on plant mixing, and tests are conducted to confirm this.

Central-Mixed Concrete

At a central batching plant, concrete is mixed before loading into the truck mixer, which acts as an agitator during transit; for short leads or low workability, dump trucks may be used.

TYPES OF RMC PLANTS

Following are the different types of RMC plants (Figure 1) and their mixing actions:

- Dry batch concrete plant.
- Wet batch concrete plant.
- Half-wet batch concrete plant.
- Combination batch concrete plant.



Figure 1. RMC batching plant.

Ignore the blade movement at first. Then, as the drum rotates, the concrete's inner impact and its impact on the drum's interior surface cause the concrete to seem to travel up the drum's right-hand wall, as seen in Figure 2.

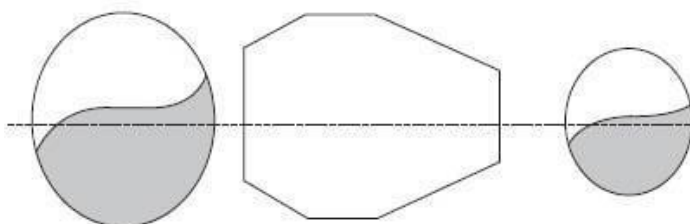


Figure 2. Cross-section of track mix action.

OBJECTIVE OF STUDY

Concrete is an important material used in construction, but mixing and handling it takes a lot of time and effort. RMC was made to save time and reduce work. Still, many builders don't fully trust RMC and use it only in a few projects. This study wants to look at how available RMC is and what happens after it's used, to help builders feel more confident using it in all types of buildings.

EQUIPMENT REQUIRED IN RMC PLANT

Inline Bin

Bins known as "inline bins" are used to hold insert raw materials, such as fine and coarse aggregates, where the material may be readily dumped by the trucks transporting fine and coarse aggregate (Figures 3, 4, and 5). An aggregate belt conveyor is used to feed the necessary aggregates (Figure 6). The aggregates are routinely weighed on the aggregate belt conveyor using a computer from the plant's computer room.

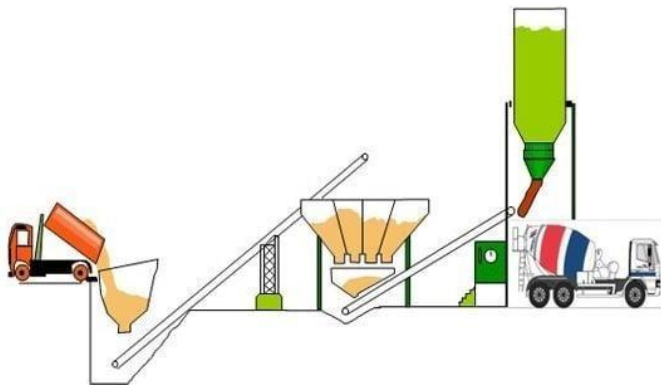


Figure 3. Dry batch RMC plant.



Figure 4. Inline bins.



Figure 5. Skip bucket (weighing belt).



Figure 6. Belt conveyer.

LITERATURE REVIEW

This study examines the cost structure of operating a RMC plant, highlighting production, delivery, and administrative expenses. Early research emphasizes the standardization of cost reporting to enhance industry-wide comparisons. Studies on expense categorization in construction businesses indicate that material costs, labor, and equipment depreciation are key financial factors influencing profitability. To increase operational efficiency, cost management strategies involving benchmarking and spending tracking are also covered in the literature. The thesis builds on these insights by proposing a systematic method for financial reporting, enabling producers to compare expenditures and optimize resource allocation. Findings contribute to cost-management strategies in the concrete industry [1].

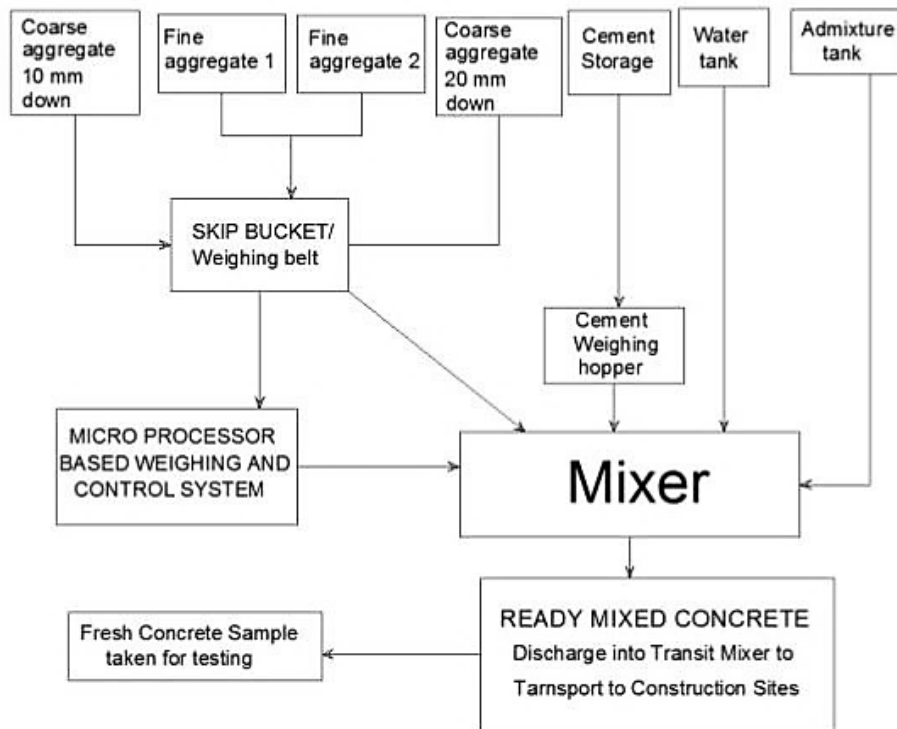
This study examines the performance evaluation standards in RMC plants, identifying key factors affecting efficiency. Using root cause analysis and Pareto diagrams, it highlights skills, strategy, systems, and administrative styles as critical influences. The research finds that management gaps, workforce training deficiencies, and incentive systems significantly impact productivity, advocating targeted improvements for performance optimization in RMC plants [2].

This study explores the history and application of Relative Importance Indices (RII) in organizational research, particularly in multiple regression analysis. It defines relative importance as the proportionate contribution of each predictor to the overall model and evaluates various methodologies, including dominance analysis and relative weights. Early research highlights limitations of traditional regression coefficients in assessing importance, emphasizing multicollinearity issues. The study provides a comprehensive review of effective measures and their relevance in industrial/organizational psychology, improving decision-making in predictor selection for complex datasets [3].

This study examines the optimization of RMC delivery operations using inventory control and discrete event simulation (DES). The literature highlights the impact of dispatch scheduling on operational efficiency, with prior research emphasizing traffic uncertainty and unloading delays as major challenges. Studies on Just-In-Time (JIT) and Lean Construction frameworks suggest minimizing idle time and maintaining supply continuity. The research integrates inventory policies and DES modeling, demonstrating that flexible dispatching strategies can enhance truck utilization, reduce queuing time, and optimize supply chain performance [4].

This study investigates the mechanical, durability, and environmental impacts of using reclaimed water in concrete production, as well as its effects on the environmental Life Cycle Assessment (LCA). Literature notes the benefits of reclaimed water in addressing water scarcity and lowering CO₂ emissions, although there are worries about its impact on compressive strength and chloride ion penetration. It is noted that the addition of silica fume improves durability and mechanical strength while also reducing global warming potential (GWP). It is suggested that a controlled approach to cement replacement in conjunction with alternate water sources aids in sustainable concrete production while minimizing environmental impacts and preserving structural performance [5].

This research investigates the development and adoption of RMC, paying particular attention to its history, benefits, and drawbacks in construction. Literature discusses the advancement of mechanization in concrete production, marking the spread of the 1930s' rotary mixer to current automated batching systems. RMC is commended for its productivity, quality, and environmental impacts, but high transportation costs and pricing remain obstacles. Studies discuss systems for admixture technologies, batching, and interdisciplinary frameworks, calling for the use of advanced materials alongside digital system integration (Figure 7) [6].



- Inert raw material namely fine aggregate and coarse aggregate are stored in bins, where as cement is stored in hopper.
- Water and admixtures are stored in tanks. The inert raw materials are fed to the batching plant mixer by means of an aggregate belt conveyor.
- The required quantity cement is extracted by screw conveyor and fed into the mixer.
- Water and admixture are pumped into the mixer by weight. After the mixing is completed, the ready mixed concrete is discharges into the transit mixer which can then transport the concrete to the construction site.
- All these above operation are controlled by a computer housed in the control room of the batching plant.

Figure 7. Manufacturing process of RMC.

Concrete Testing

Slump Test

To test concrete uniformity (max aggregate 38 mm), clean and dry the mold, then place it on a flat, stiff surface (Figure 8a). Fill the mold in four equal layers, tamping each 25 times evenly with a rod that penetrates the previous layers. Fully tamp the bottom layer.

After tamping the top layer, level the concrete and remove any mortar leaked out. Lift the mold carefully to let the concrete settle and measure the slump by the difference in height. Complete these steps within two minutes in a vibration-free area (Figure 8b) [7].

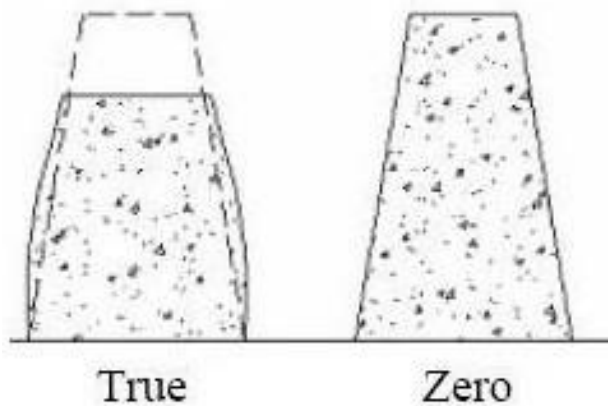


Figure 8. (a) Types of concrete slump test results.

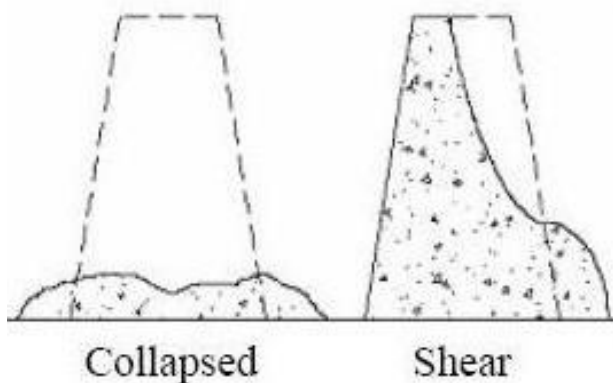


Figure 8. (b) Types of concrete slump test results.

Compacting Factor Test

This outlines a method for figuring out if concrete is workable when the aggregate's nominal maximum size is less than 38 mm. Although the test's primary application is in the lab, it can also be utilized in the field if conditions allow. More accurate and sensitive than the slump test, it is especially helpful for concrete mixes with extremely poor workability, which are typically employed when vibration is used to compress the concrete; these concretes may frequently fail to slump [8].

Using the hand scoop, carefully deposit the concrete sample to be analyzed in the top hopper. The trapdoor must be opened to allow the concrete to fall into the lower hopper when the hopper has been filled level with its brim. Some mixtures are prone to becoming lodged in one or both hoppers. Pushing against the concrete from the top may assist the concrete to pass through if this happens. The trowels must be used to cover the cylinder throughout this procedure. The cylinder must be unlocked, the bottom hopper's trapdoor must be opened, and the concrete must be allowed to fall into the cylinder as soon as it has settled [9].

The extra concrete that is still over the cylinder's top will next be removed by sliding the blades concurrently from each side across the top of the cylinder while applying pressure to the top edge. This will be done while holding a trowel in each hand with the blades' surfaces horizontal. The exterior of the cylinder must then be cleaned. The weight of the concrete in the cylinder must be determined to the nearest 10 g, or the aforementioned process must be carried out in a vibration-free environment. We will call this weight the partially pressed concrete weight [10].

The same sample of concrete must be used to refill the cylinder in layers that are around 5 cm deep. To achieve complete compaction, the layers must be firmly rammed or, better still, vibrated. Carefully strike the top surface of the fully compacted concrete off level with the cylinder's top. Next, the cylinder's outside will be cleaned. The test has a high enough sensitivity to determine variations in workability that result from the cement's first hydration processes. So, if precisely similar findings are to be produced, each test should be performed at a consistent time gap after the mixing has finished.

Factors Affecting the Choice of Mix Proportions

- Compressive strength
- Workability
- Durability
- Maximum nominal size of aggregate
- Grading and type of aggregate
- Quality Control

CHARACTERISTICS OF CONCRETE

Concrete must acquire specific physical and chemical characteristics during the hydration and hardening processes. Mechanical strength, low moisture permeability, and chemical and volumetric stability are essential characteristics.

Workability

The capacity of a new concrete mix to fill the form or mould correctly with the necessary work without lowering the quality of the concrete is known as workability. Workability may be altered by adding chemical admixtures and is dependent on the cementitious composition, age (degree of hydration), aggregate (shape and size distribution), and water content. Concrete workability can be improved by adding chemical admixtures or increasing the water content. The quality of the final concrete will be worse due to raised leaking (surface water) and/or aggregate segregation (when the cement and aggregates begin to separate). A highly harsh mix design with a very low slump can be produced by using an aggregate with an undesired gradation; this cannot be easily made more feasible by adding appropriate quantities of water.

Strength

Although concrete has a relatively high compressive strength, its tensile strength is only around 10% of its compressive strength. Therefore, even when loaded in compression, concrete would almost invariably fail from tensile stresses without correcting. The practical implication of this is that concrete components that are exposed to tensile stresses need to be reinforced with materials that are strong in tension. The most common use of steel reinforcement is in concrete construction. The reinforcement, which provides the required tensile strength to the concrete, might be structural fibres, mesh, or bars (rebar). Beams or slabs alone can be made possible by prestressing concrete, which lowers tensile stress, utilizing internal steel cables, or tendons. The employment of tools, like a Schmidt hammer, which is used to gauge the strength of concrete, can make non-destructive inspections of concrete buildings possible. The water-cementitious ratio (w/cm), the design elements, and the methods for mixing, pouring, and curing all have an impact on the concrete's ultimate strength. Concrete with a smaller cementitious (water-to-cement) ratio is stronger than concrete with a higher ratio.

Elasticity

The relative ratios of the modulus of elasticity of the cement matrix and particles determine the modulus of elasticity of concrete. When matrix cracking occurs, the concrete's modulus of elasticity becomes more non-linear, while it is still comparatively linear at low stress levels.

Expansion and Shrinkage

The coefficient of thermal expansion of concrete is quite low. Nevertheless, if expansion is not allowed for, extremely high forces may be generated, which might lead to cracks in areas of the structure

that cannot sustain the force or the continual cycles of expansion and contraction. Although the rate of shrinkage decreases very fast and keeps decreasing over time, concrete continues to shrink as it ages because of the continuous reaction occurring in the cement. When the two types of building come into contact, the relative expansion and shrinkage of masonry and concrete must be carefully accommodated. It is widely acknowledged that concrete will never expand to its original volume under heat loading since it continues to shrink for years after it is first laid.

Shrinkage Cracking

The coefficient of thermal expansion of concrete is quite low. Nevertheless, if expansion is not allowed for, extremely high forces may be generated, which might lead to cracks in areas of the structure that cannot sustain the force or the repeated cycles of expansion and contraction. Although the rate of shrinkage decreases very fast and keeps decreasing over time, concrete continues to shrink as it ages because of the continuous reaction occurring in the material. When the two types of building come into contact, the relative expansion and shrinkage of brickwork and concrete must be carefully accommodated. It is widely acknowledged that concrete will never grow to its original volume under heat loading since it continues to shrink for years after it is first laid.

Creep

Creep is the word used to characterize a material's constant movement or distortion that relieves internal tensions. Concrete is prone to creep when exposed to long-duration stresses. Creep is not caused by short-duration forces like wind or earthquakes. Although creep must be managed, it can occasionally lessen the amount of cracking that happens in a concrete building or part. In concrete constructions, the quantity of remaining reinforcing helps to lessen shrinkage, creep, and cracking.

RESEARCH METHODOLOGY

The primary goal of the study is to identify the important elements influencing digital transformation measurement in building construction projects and evaluate the practice of technological change in RMC evaluation in building construction projects. After reviewing various relevant publications, the following study approach is used to observe building construction activities. To determine the real practices regarding digital transformation, time, and cost in building construction projects, as well as the crucial elements influencing technological advancement in building construction assignments, actual data is gathered and examined.

Data may be gathered in a variety of ways. The methods of observation, interviews, surveys, and timetables are important. We use questionnaires to gather data for this study. This approach to gathering data is very common, especially for large-scale investigations. This approach involves sending a questionnaire to the individual in issue, asking them to respond and send the completed forms back. A questionnaire is made up of several questions that are written or printed on a form or series of forms in a certain order.

Survey Questionnaires

The research tool utilized in this study is a questionnaire that was created to guarantee that it addressed the study's goals, which were divided into various sections. The purpose of the first section of the questionnaire is to collect information about the respondents and the firm profile. The questions in this section were designed to collect data on the respondents' employment position, career knowledge, and contact details for projects. The purpose of the questionnaire's second section is to gather information on contractors' knowledge and comprehension of productivity in building projects.

The third section includes the different productivity-affecting elements that the respondents are asked to rank, as well as general experiences that have been used to increase productivity and suggestions that have been put forth to increase productivity on building projects. The parameters found in earlier studies will serve as the foundation for creating a questionnaire that will examine their impact on the construction sector's efficiency. The questionnaire was designed with the need that it be easy for

respondents to grasp, straightforward, and uncomplicated, while also being able to be properly understood by the researcher.

Primary Data

- Interviews with vendors, engineers, and industry professionals to learn about their viewpoints on digital transformation.
- Surveys of construction companies to assess the advantages, difficulties, and rates of digital technology implementation in RMC.
- To evaluate digital integration, field inspections of concrete shipping and batching plants are conducted.

Secondary Data

Review of the body of research on digital developments in the concrete industry, including journal papers, technical reports, and current literature. Examination of business case studies demonstrating automated transportation, AI-based quality control, and intelligent batching facilities.

Reports from the government and business sectors about RMC's digital efforts, regulations, and market trends. Targeting important stakeholders, including suppliers, batching plant operators, and construction businesses, the study uses survey-based data collection. Surveys concentrate on how they see and use digital tools, such as real-time monitoring software, AI-based quality assurance systems, and batching machines, enabled by the Internet of Things.

Furthermore, conducting structured interviews with professionals in the field offers a greater understanding of the advantages and difficulties of putting digital solutions into practice.

Questionnaire Design

The questionnaire is created using the study methodology that will be applied following a comprehensive review of the literature and the identification of several variables influencing labor productivity in building construction. There are two sections to the questionnaire.

The company and responder profile information is covered in the first section, while the primary questionnaire is covered in the second. It includes 46 parameters that impact labor productivity in building construction, divided into 10 major areas. Respondents are required to select only one option and simply offer their view on each component based on their knowledge, expertise, and experience.

The questionnaire's design required respondents to assess the regularity of occurrence on a scale of one to four and the intensity of effect on a range of one to five in order to rate both factors.

Survey Work and Data Collection

Within the confines of the study, the survey will be administered to the selected respondents in the sample. Surveys will be distributed to participants, and data will be collected from the forms they fill out. The purpose of these surveys is to find out what respondents think about the factors impacting RMC's digital revolution.

DATA COLLECTION AND DATA ANALYSIS

Explanation of RII and Average Ratings

The RII is used to determine the importance of various factors based on survey responses. The RII formula is

$$RII = (\Sigma W) / (A \times N), \tag{1}$$

where:

ΣW = Sum of weights (ratings);

A = Maximum possible rating (5 in this case); and
N = Number of respondents who answered the question.

The RII score ranges between 0 and 1, with higher values indicating greater perceived importance.

Average Ratings represent the mean score given by all respondents to a specific question. It is a simple metric to gauge the overall perception of the factor without normalization.

Questionary Form

Survey Title: Digital Transformation of RMC in Gujarat.

Section 1: Respondent Information.

Name (Optional): _____

Designation: _____

Years of Experience in RMC: <5 5–10 11–15 >15

Type of Organization: RMC Plant Contractor Consultant Supplier Other:

Region/District in Gujarat: _____

Please rate each factor on a scale of 1 to 5:

1 = Not Important 2 = Slightly Important 3 = Moderately Important 4 = Important 5 = Very Important

Section 2: Factors Influencing Digital Transformation.

Main Criteria

Technological Infrastructure (Table 1).

Table 1. Technological infrastructure.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
1	Availability of digital tools and software <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
2	Internet connectivity & speed at plant sites <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
3	Compatibility of software across departments <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
4	Integration of ERP systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
5	Use of GPS for fleet tracking <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
6	Adoption of IoT in batching systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
7	Mobile apps are used by site engineers <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Organizational Readiness (Table 2).

Table 2. Organizational readiness.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
8	Management support for digital initiatives <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
9	Existence of a digital transformation roadmap <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
10	Willingness of top leadership to invest in IT <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
11	Staff training and technical skills <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
12	Internal change management capability <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
13	Clear internal communication about digital tools <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
14	IT literacy of site supervisors <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Financial considerations (Table 3).

Table 3. Financial considerations.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
15	Cost of implementation of digital systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
16	ROI on digital investments <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
17	Availability of budget for tech upgrades <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
18	Cost of software licensing and maintenance <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
19	Availability of external funding/incentives <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Operational Benefits (Table 4).

Table 4. Operational benefits.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
20	Improved production efficiency <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
21	Real-time tracking of concrete delivery <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
22	Reduction in manual errors <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
23	Better resource allocation through data analytics <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
24	Enhanced quality control & consistency <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
25	Faster decision-making <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
26	Automation in dispatch scheduling <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Human and Cultural Factors (Table 5).

Table 5. Human and cultural factors.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
27	Resistance to change among staff <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
28	Digital skill gap in workforce <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
29	Union or labor body resistance <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
30	Language barriers with digital tools <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
31	User-friendliness of digital systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

External Support & Policy (Table 6).

Table 6. External support & policy.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
32	Support from IT vendors <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
33	After-sales service by tech providers <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
34	Technical helpdesk availability <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
35	Availability of local tech experts in Gujarat <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
36	Regulatory or government incentives <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
37	Role of Gujarat state policies in digitization <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Integration and Security (Table 7).

Table 7. Integration and security.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
38	Integration with existing systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
39	Real-time data synchronization <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
40	Cybersecurity risks and threats <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
41	Data privacy laws and compliance <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
42	Cloud-based data backup systems <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Competitive and Market Influence (Table 8).

Table 8. Competitive and market influence.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
43	Competitor pressure to digitize <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
44	Client demand for real-time tracking <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
45	Digital reputation in the Gujarat market <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Main Criteria

Future Readiness (Table 9).

Table 9. Future readiness.

No.	Sub-Factor and Rating (<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5)
46	Openness to AI/ML in production monitoring <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
47	Blockchain for supply chain transparency <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
48	Smart sensors for strength monitoring <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
49	Digital twin modeling for batch plants <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
50	Sustainability tracking using digital tools <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

Full RII Table (Table 10).

Table 10. Factors and RII score.

Question	Sub-Factor	RII Score
Q1	Availability of digital tools and software	0.5804
Q2	Internet connectivity & speed at plant sites	0.5967
Q3	Compatibility of software across departments	0.648
Q4	Integration of ERP systems	0.5898
Q5	Use of GPS for fleet tracking	0.6271
Q6	Adoption of IoT in batching systems	0.5758
Q7	Mobile app use by site engineers	0.6131
Q8	Management support for digital initiatives	0.6177
Q9	Existence of a digital transformation roadmap	0.6014
Q10	Willingness of top leadership to invest in IT	0.5944
Q11	Staff training and technical skills	0.6247
Q12	Internal change management capability	0.6084

Q13	Clear internal communication about digital tools	0.5571
Q14	IT literacy of site supervisors	0.5967
Q15	Cost of implementation of digital systems	0.6247
Q16	ROI on digital investments	0.6597
Q17	Availability of budget for tech upgrades	0.5781
Q18	Cost of software licensing and maintenance	0.5478
Q19	Availability of external funding/incentives	0.5991
Q20	Improved production efficiency	0.5898
Q21	Real-time tracking of concrete delivery	0.6271
Q22	Reduction in manual errors	0.6061
Q23	Better resource allocation through data analytics	0.6037
Q24	Enhanced quality control & consistency	0.5781
Q25	Faster decision-making	0.5758
Q26	Automation in dispatch scheduling	0.5478
Q27	Resistance to change among staff	0.5781
Q28	Digital skill gap in the workforce	0.5828
Q29	Union or labor body	0.5291
Q30	Language barriers with digital tools	0.5851
Q31	User-friendliness of digital systems	0.5804
Q32	Support from IT vendors	0.5758
Q33	After-sales service by tech providers	0.5175
Q34	Technical helpdesk availability	0.5734
Q35	Availability of local tech experts in Gujarat	0.5688
Q36	Regulatory or government incentives	0.6154
Q37	Role of Gujarat state policies in digitization	0.6294
Q38	Integration with existing systems	0.6037
Q39	Real-time data synchronization	0.5991
Q40	Cybersecurity risks and threats	0.5408
Q41	Data privacy laws and compliance	0.6294
Q42	Cloud-based data backup systems	0.6014
Q43	Competitor pressure to digitize	0.5618
Q44	Client demand for real-time tracking	0.5641
Q45	Digital reputation in the Gujarat market	0.6131
Q46	Openness to AI/ML in production monitoring	0.6037
Q47	Blockchain for supply chain transparency	0.5851
Q48	Smart sensors for strength monitoring	0.5711
Q49	Digital twin modeling for batch plants	0.6434
Q50	Sustainability tracking using digital tools	0.5734

Detailed RII Calculations (Table 11).

Table 11. The raw calculations used to derive the RII score.

Question	Sub-factor	Total Score (ΣW)	Respondents (N)	Max Rating (A)	RII
Q1	Availability of digital tools and software	249.58588235294118	86	5	0.5804
Q2	Internet connectivity & speed at plant sites	256.6023529411765	86	5	0.5967
Q3	Compatibility of software across departments	278.6541176470588	86	5	0.648

Q4	Integration of ERP systems	253.59529411764706	86	5	0.5898
Q5	Use of GPS for fleet tracking	269.6329411764706	86	5	0.6271
Q6	Adoption of IoT in batching systems	247.58117647058825	86	5	0.5758
Q7	Mobile app use by site engineers	263.61882352941177	86	5	0.6131
Q8	Management support for digital initiatives	265.6235294117647	86	5	0.6177
Q9	Existence of a digital transformation roadmap	258.6070588235294	86	5	0.6014
Q10	Willingness of top leadership to invest in IT	255.6	86	5	0.5944
Q11	Staff training and technical skills	268.6305882352941	86	5	0.6247
Q12	Internal change management capability	261.61411764705883	86	5	0.6084
Q13	Clear internal communication about digital tools	239.56235294117647	86	5	0.5571
Q14	IT literacy of site supervisors	256.6023529411765	86	5	0.5967
Q15	Cost of implementation of digital systems	268.6305882352941	86	5	0.6247
Q16	ROI on digital investments	283.6658823529412	86	5	0.6597
Q17	Availability of budget for tech upgrades	248.58352941176472	86	5	0.5781
Q18	Cost of software licensing and maintenance	235.5529411764706	86	5	0.5478
Q19	Availability of external funding/incentives	257.60470588235296	86	5	0.5991
Q20	Improved production efficiency	253.59529411764706	86	5	0.5898
Q21	Real-time tracking of concrete delivery	269.6329411764706	86	5	0.6271
Q22	Reduction in manual errors	260.61176470588236	86	5	0.6061
Q23	Better resource allocation through data analytics	259.6094117647059	86	5	0.6037
Q24	Enhanced quality control & consistency	248.58352941176472	86	5	0.5781
Q25	Faster decision-making	247.58117647058825	86	5	0.5758
Q26	Automation in dispatch scheduling	235.5529411764706	86	5	0.5478
Q27	Resistance to change among staff	248.58352941176472	86	5	0.5781
Q28	Digital skill gap in the workforce	250.58823529411765	86	5	0.5828
Q29	Union or labor body resistance	227.53411764705882	86	5	0.5291

Q30	Language barriers with digital tools	251.59058823529412	86	5	0.5851
Q31	User-friendliness of digital systems	249.58588235294118	86	5	0.5804
Q32	Support from IT vendors	247.58117647058825	86	5	0.5758
Q33	After-sales service by tech providers	222.52235294117648	86	5	0.5175
Q34	Technical helpdesk availability	246.57882352941178	86	5	0.5734
Q35	Availability of local tech experts in Gujarat	244.5741176470588	86	5	0.5688
Q36	Regulatory or government incentives	264.62117647058824	86	5	0.6154
Q37	Role of Gujarat state policies in digitization	270.63529411764705	86	5	0.6294
Q38	Integration with existing systems	259.6094117647059	86	5	0.6037
Q39	Real-time data synchronization	257.60470588235296	86	5	0.5991
Q40	Cybersecurity risks and threats	232.54588235294116	86	5	0.5408
Q41	Data privacy laws and compliance	270.63529411764705	86	5	0.6294
Q42	Cloud-based data backup systems	258.6070588235294	86	5	0.6014
Q43	Competitor pressure to digitize	241.5670588235294	86	5	0.5618
Q44	Client demand for real-time tracking	242.56941176470588	86	5	0.5641
Q45	Digital reputation in the Gujarat market	263.61882352941177	86	5	0.6131
Q46	Openness to AI/ML in production monitoring	259.6094117647059	86	5	0.6037
Q47	Blockchain for supply chain transparency	251.59058823529412	86	5	0.5851
Q48	Smart sensors for strength monitoring	245.57647058823528	86	5	0.5711
Q49	Digital twin modeling for batch plants	276.64941176470586	86	5	0.6434
Q50	Sustainability tracking using digital tools	246.57882352941178	86	5	0.5734

Correlation Matrix of First 10 Questions

This heatmap displays (Figure 9) how ratings of the first 10 questions correlate with one another. Positive correlations indicate that participants who rated one factor highly also tended to rate others similarly. Strong correlations might suggest related factors, while weak or negative ones indicate distinct perceptions.

Correlation Matrix of Top 10 Highest RII Factors

This heatmap displays (Figure 10) the correlation between the top 10 highest RII-rated survey factors. It helps identify which high-priority factors tend to be rated similarly by respondents. Strong positive correlations indicate factors that are often perceived in a similar way, while weaker or negative correlations suggest distinct areas of concern.

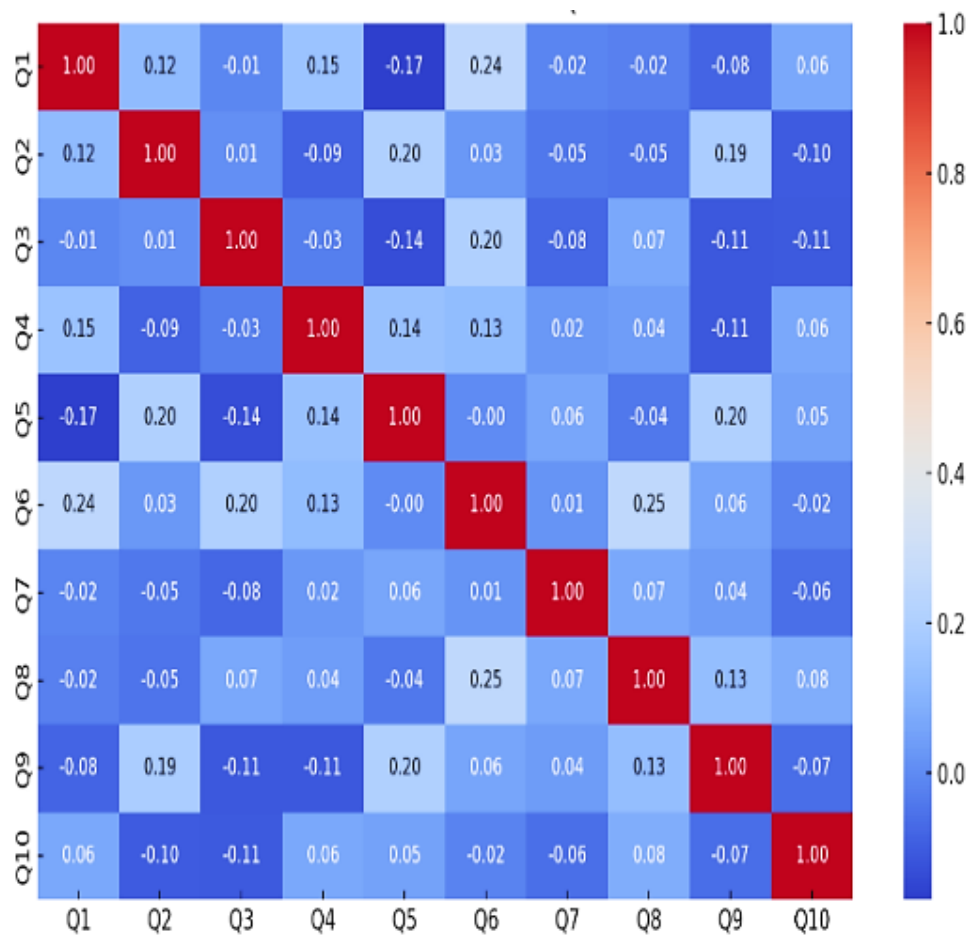


Figure 9. Correlation matrix of the first 10 questions.

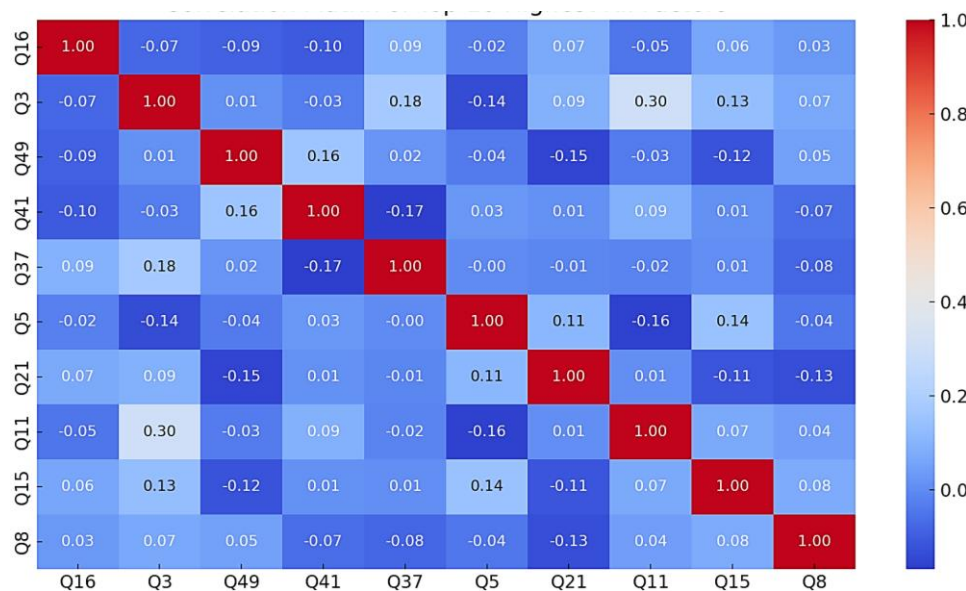


Figure 10. Correlation matrix of the top 10 highest RII factors.

Average Ratings Across All Questions

This chart (Figure 11) illustrates the average rating for each of the 50 questions in the survey. Higher bars signify questions that received stronger agreement or satisfaction, pointing to their perceived importance. This visualization helps compare how factors rank on average across all participants.

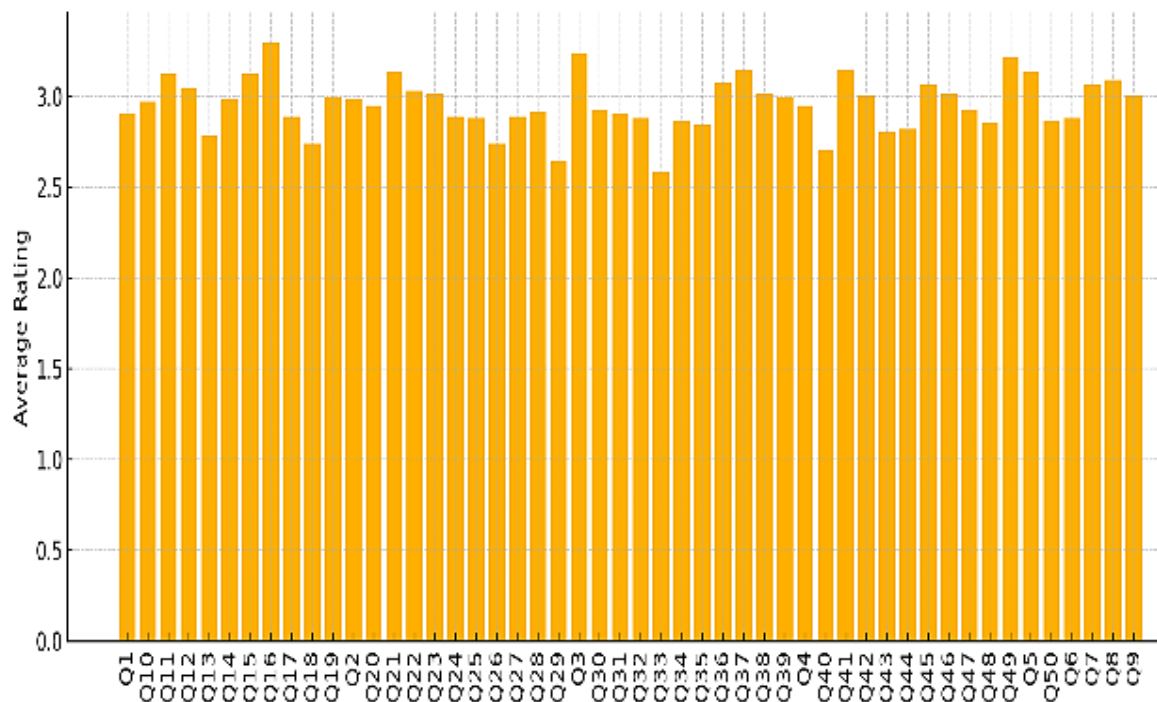


Figure 11. Average rating of all questions.

Top 10 Sub-Factors by RII Score

The chart (Figure 12) above illustrates the top 10 most important sub-factors based on their RII scores.

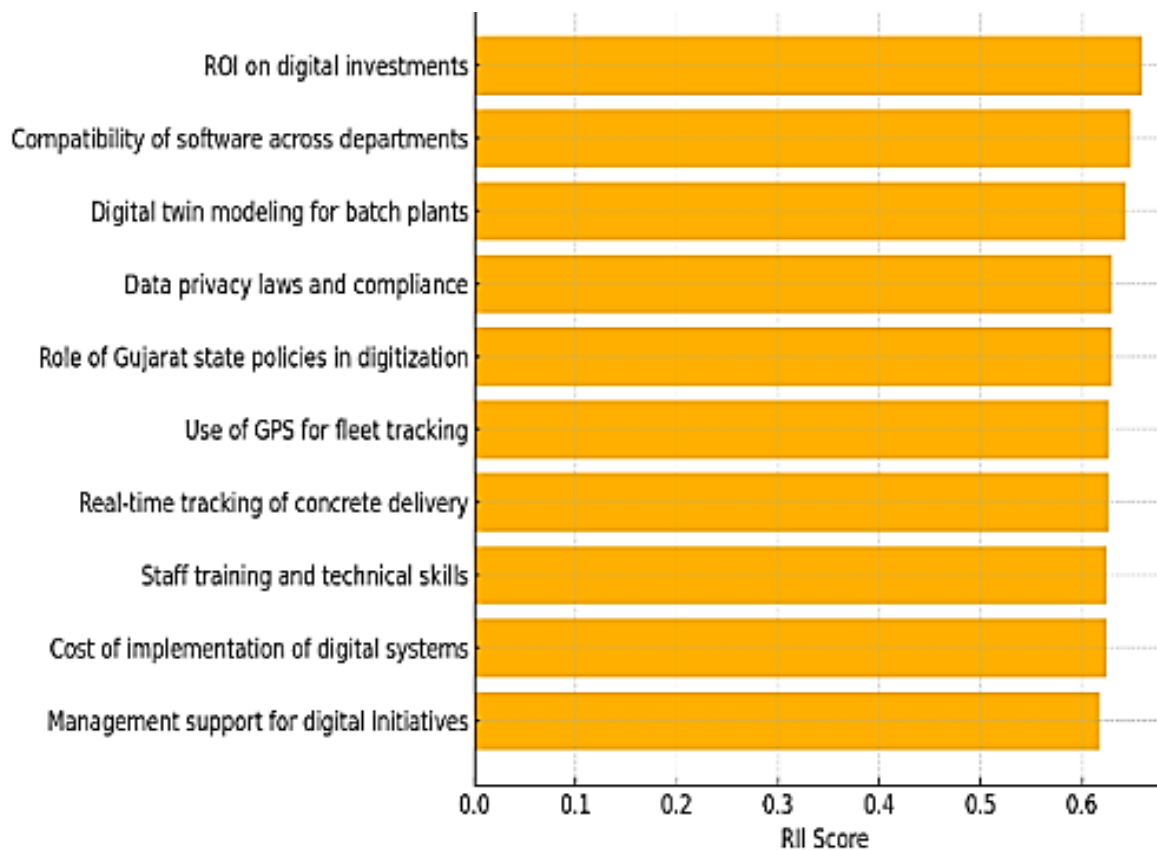


Figure 12. Top 10 sub-factors.

Rating Distribution for Q16: ROI on Digital Investments

This bar chart (Figure 13) shows the distribution of ratings provided by respondents for the factor 'ROI on digital investments'. It helps identify whether most respondents found ROI highly important (e.g., ratings of 4 or 5) or were divided in their opinions. A skewed distribution indicates strong consensus, while a flatter distribution suggests mixed views.

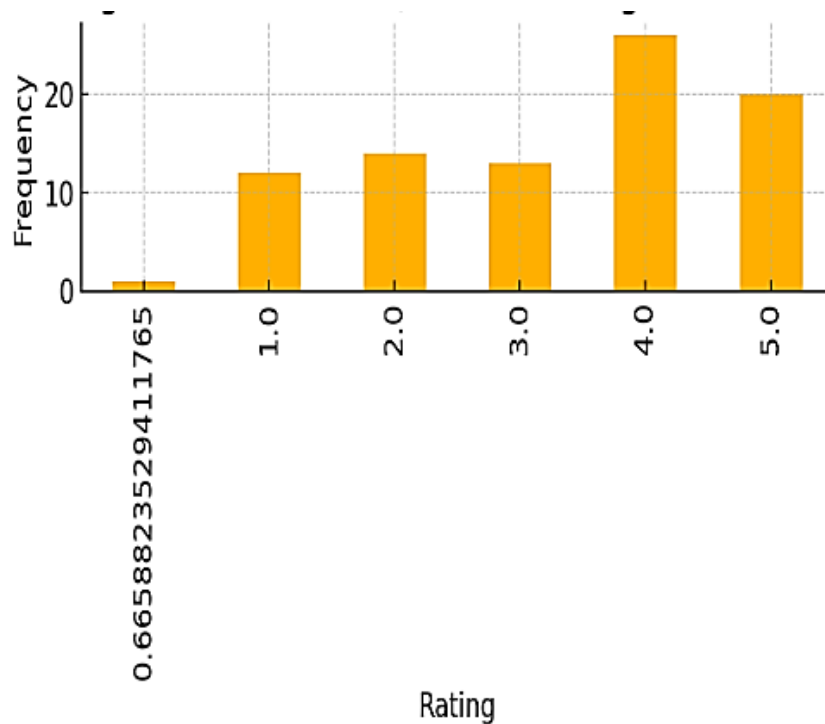


Figure 13. Rating distribution for Q16.

Designation-Wise Average Rating for Q16

This chart (Figure 14) reveals how respondents from various job roles (such as managers, engineers, consultants) rated the ROI of digital investments. It helps uncover role-based differences in perception – such as whether managerial staff place more emphasis on ROI than technical staff.

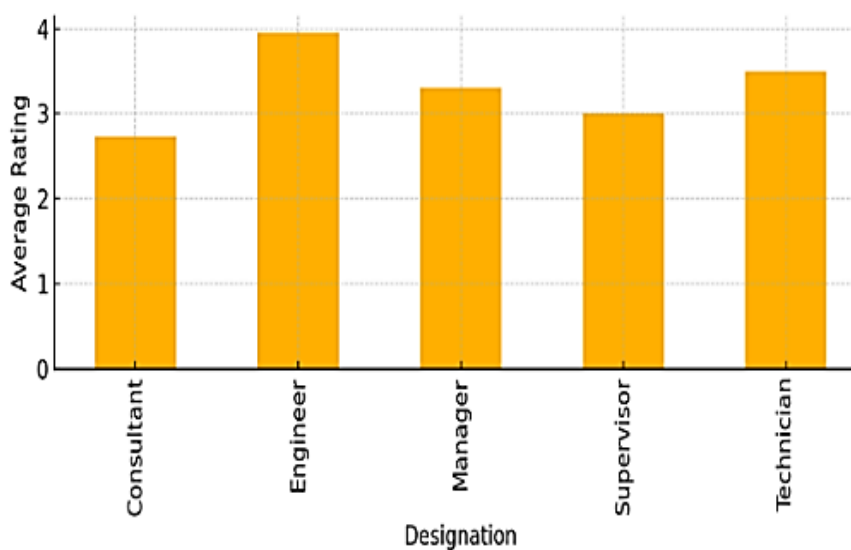


Figure 14. Designation-wise average.

Rating for Q16

Comparison of RII vs Average Rating (Top 10 Factors)

This chart (Figure 15) compares the RII and average rating scores for the top 10 sub-factors. While average ratings reflect direct respondent feedback, RII accounts for normalization by the number of responses and maximum score. This comparison reveals whether perceived importance (RII) aligns with average sentiment or if differences exist.

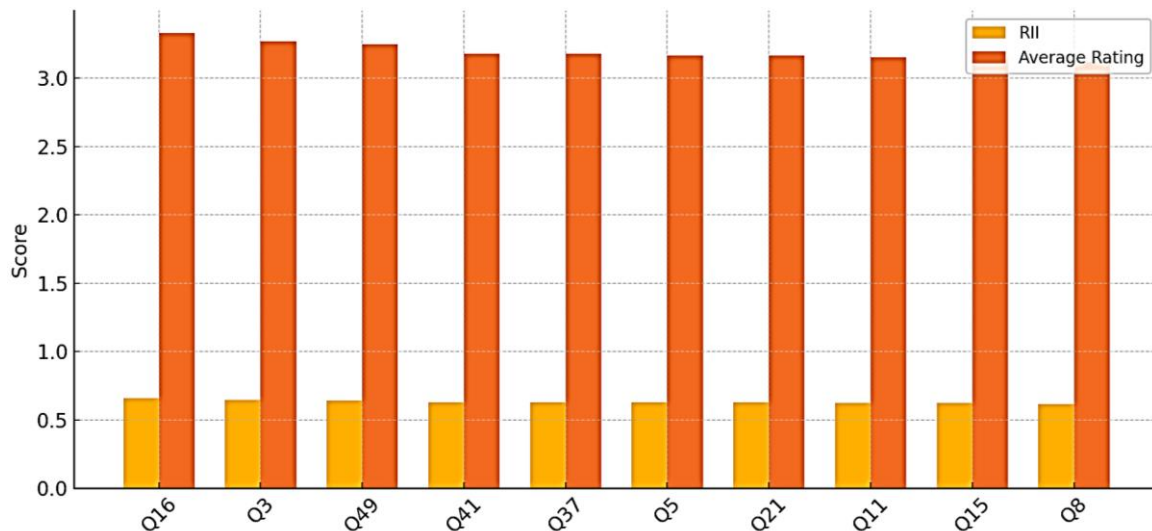


Figure 15. Comparison of RII vs average rating.

CONCLUSIONS

- Companies are not just chasing tech trends; they want proof that digital investments will not turn into expensive paperweights.
- Software systems need to work together seamlessly – because no one wants their departments to speak different digital dialects.
- Data privacy and compliance are high on the priority list. After all, violating regulations is a faster way to fame than innovating.
- Management support is critical – if leadership is not on board, digital transformation is just a fancy Wishlist gathering dust.
- Real-time tracking and efficiency boosts? Yes, please! Nobody wants to act detective just to figure out where their concrete delivery went.
- Human challenges? Moderate. Some folks embrace change, while others resist it like a cat avoiding a bath – cue the need for training and change management.
- External tech support matters – because every company needs an IT wizard to untangle digital messes.

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