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**Ganesh Kumar Kantak, Mukesh
Kumar**

Department of Mechanical Engineering,
Vivekananda Global University, Jaipur, India

ASSESSMENT AND PRIORITIZATION OF INDUSTRY 4.0 ADOPTION BARRIERS IN RAJASTHAN'S DAIRY AND HORTICULTURE SUPPLY CHAINS USING MULTI-CRITERIA DECISION APPROACH

Ganesh Kumar Kantak, Mukesh Kumar

Department of Mechanical Engineering, Vivekananda Global University, Jaipur, India

Abstract: *The dairy and horticulture industries constitute a significant portion of the Agri-based economy in Rajasthan, but the supply chains in these industries are not digitalized. Though Industry 4.0 technologies have a potential to improve traceability, minimize losses and make decisions smarter, penetration into these sectors is low and disproportionate. This paper discussed the extent to which these supply chains are ready to undergo digital transformation and the top barriers that have been stopping the process. A survey was done among 100 stakeholders who were comprised of farmers, members of cooperatives, processing units, logistics operators and supply chain managers. An overall preparedness framework was created that included three overall enablers, nine assessment criteria, and fifty four attributes in detail that covered the dimensions of technology, organization, humans, market, and sustainability. As stakeholder ratings are subjective and inaccurate, the degree of each barrier was assessed through a fuzzy multi-criteria approach to decision making. This analysis uncovered thirty one attributes as significant barriers to Industry 4.0 adoption. Among the critical technological gaps, there were the lack of digital traceability systems, sub-optimization of smart sensors, sub-optimization of cold-chain monitoring, and predictive maintenance in processing facilities. Human and organizational issues were also important, including the lack of digital literacy, change resistance, slow-paced technology-related decision-making, and the lack of professional technical staff. Market and policy considerations were also identified to be an issue such as poor knowledge of government support programmes, middlemen price fixing and poor coordination between the supply chain players. The pressure of the environment especially heat stress and post-harvest spoilage only augmented the need of smart and data-driven systems. The findings provide a definite guideline to policymakers and stakeholders in the industry with the ambition of hastening the process of implementing Industry 4.0 in the perishable supply chains in Rajasthan.*

Keywords: *Industry 4.0 Readiness, Supply Chain Barriers, Dairy Industry Rajasthan, Horticulture Supply Chain*

1. Introduction

Forts and desert are not the only things that are famous in Rajasthan. It is even run silently on cows, milk cans, carts of fruits and vegetables heading to the closest mandi the life bloods of

its horticulture and dairy supply chains. They do not necessarily receive the limelight, but have to do the hard work in terms of rural income and jobs. Herein lies the rub, you see, these are the industries that are supposed to be on fire at this point in time, and technology is taking an incredibly fast leap. To us, it is now the era of Industry 4.0 smart sensors, data analytics, automation, robots, AI, blockchain, and all those buzzwords everybody is busy throwing around. But, what of the real agricultural life of Rajasthan? Not all of those tools have come out of the buzzwords. The gap in the research is quite evident. On the one hand, there is a world where the milk will be tracked down to the udder and to the delivery application at the touch of a button. Over there, the farmers are not yet certain whether the milk truck will even arrive on time today or it will even be possible to get their goods to the market before they have to spoil. We are speaking of post-harvest losses which make everybody wince. Fruits and vegetables do not stand long under 40-45degC heat and milk will not stand awaiting infrastructure to join in. In the absence of well-known cold chains, in the absence of expedited delivery, in the absence of real-time tracking, much of the value is literally vaporized. Farmers lose money. Consumers pay more. And the entire supply chain continues to hobble.

Afterwards, there is the digital divide. IoT monitoring? Predictive maintenance? Blockchain traceability? This is not a tech starter kit that most small and marginal farmers have been given in Jaipur and the nearby districts. Others still have recourse to age-old experience and gut nothing wrong about this but difficult at times when market prices are flip-flopping and the information players take up the start. And honesty will tell one thing: not all people trust machines, application, or some so-called cloud platforms they have never laid their eyes on. Others can just not afford them. Even individuals who intend to upgrade find themselves at the starting block with no knowledge, no application, and no funding. It gets trickier. Even the market structure is against a number of growers. More than not, prices are controlled by middlemen and these chains of dependency deprive of transparency and bargaining power. Payments get delayed. Farmers accept the price they receive as it is the other option. There is a great deal of policy push, trusted digital marketplaces, easy access to incentives or subsidies and without that, the promise of Industry 4.0 serves as an extremely distant thing of a prosperous urban fantasy that had completely left out the villages.

Herein is where present study, therefore, comes in. Rather than merely marketing the virtues of intelligent agriculture, in the current research the place of the industry 4.0 in the prescribed dairy and horticulture sector was examined: What is keeping the horticulture and dairy supply chains of Rajasthan digitally empowered in the first place? And when we know that, how

prepared are they themselves to accept these Industry 4.0 technologies? In order to bring this to life not merely a Jaipur district experiment was made. It is a thriving city with strong rural agricultural backgrounds. A sort of an ideal transitional zone between traditional and modern. We interviewed 100 stakeholders throughout the chain: farmers, dairy employees, processors, transport participants, market officials, literally the people who have to cope with the real headaches on an hour-by-hour basis. They answered us on what makes them sluggish, what frightens them about technology and what they hope that someone can do something about sooner. We constructed a formal assessment system throughout the process; 3 key enablers, 9 criteria and 54 specific barriers/ attributes because the assessment would not be mere opinion-based. This encompassed all the internet connectivity to leadership decision, the cold storage and clarity of government policies. And since the judgments of people can hardly be sharp and black-or-white, we employed the Fuzzy Multi-Criteria Decision-Making (F-MCDM) methods. It enabled us to translate those fuzzy phrases such as this is kind of bad or that is extremely difficult into the readiness scores to be quantified.

2. Literature Review

The recent years had seen digital transformation in agriculture taking the attention of most people worldwide. Scholars all over were investigating the ways in which technologies such as IoT, AI, automation, and blockchain are driving supply chains to the forefront. However, unexpectedly, once we turned our eyes toward Rajasthan, and particularly, dairy and horticulture, there was not much on the literary lines. It was as though and everybody was chatting smart farming in some different place yet farmers here were still grappling with the old headaches. The available literature demonstrated that Industry 4.0 was not a mere buzzword. Indicatively, Abdul Jabbar et al. (2024) discussed how blockchain enhances transparency and trust in the supply chains. It is a very valid argument, since the trust normally leaves somewhere between farmer and consumer. Xu and Dong (2024) addressed the issue of digital transformation as the contributor to low-carbon development. Nice. Cleaner tech. Cleaner future. Another aspect emphasized by Gupta et al. (2024) is the way digital innovation continues to transform business activities in industries. All fine ideas. However, once again-- the research articles were focused mainly on developed systems, where technological adoption was not such a big struggle.

It also had works which were more inclined towards logistics and agriculture. Rawat et al. (2024) evaluated the of logistics companies that were ready to the back-up of cyber-physical

systems. It foreshadowed its preparation analysis--that this research required earnestly. In fact, Zhao et al. (2024) determined obstacles in the agri-food supply chains through fuzzy approaches. Finally, right? Similar direction. Their target was also more general rather than dairy or fruits and vegetable with the specifics of the Indian climate and infrastructure. Other studies such as Silva et al. (2024) and Chanchaichujit et al. (2024) also made attempts to decode challenges of decoding transformation in fruit and vegetable supply chain with references to digital hesitations and technical discrepancies. Very familiar she sounded--farmers in the rest of Rajasthan must have felt the same. They did not oppose technology. They simply did not want to have something they cannot realize or afford. Sustainability is another trend the same we continued to see. Digital adoption, according to the studies of such scholars as Dai (2024), Borsano et al. (2024), Tajbakhsh et al. (2024), and others, was associated with more environmentally friendly results. The Industry 4.0 is equivalent to cleaner processes, more streamlined decision-making, and reduced wastage. Those were huge advantages. They were much needed in Rajasthan due to high rates of spoilage that had been consuming profits eternally. Unfortunately, such papers barely noticed the union between sustainability and technology that took place within dairy and horticulture chains in this region.

Risk and resilience papers were also in existence. Barman et al. (2024) demonstrated the ability of flexible supply chains to respond more when demand is affected by shocks. Dubey et al. (2024) researched humanitarian supply chains throughout the pandemic- of sorts, the disaster exercise of agricultural movements. All significant, yet not emphasized on local impediments in the perishable export of the state of Rajasthan. Now blockchain again. Such researchers as Sharma et al. (2024) and Kuei and Chen (2023) actually thought that blockchain was the solution to the lack of transparency. Granted, traceability is important. Consumers prefer to understand the origin of the milk or whether the vegetables were stuck in the truck during the 18 hours of sunshine. But these articles failed to demonstrate how small farmers in Rajasthan would ever find themselves on the complex systems. Another hot star had been artificial intelligence. Chen & Long (2024) and Zong and Guan (2024) highlighted the role of AI in prediction, feeling the risk, market insight, and demand types. Sounds awesome. Only to discover the articles such as Mishra et al. (2024) and Chhetri (2023) stating that the stagnation in adoptions was largely caused by the statistically significant difference in digital capabilities. Bingo. That's Rajasthan right there. Though sensors and data dashboards may have miraculous potential, who is going to read it in rural installations?

Transportation 4.0 and smart logistics were mentioned, thanks to Wong et al. (2024). They discussed structures, competition, the transformation to Industry 5.0. At the same time, dairy vehicles in sections of Jaipur district continued to follow routes according to the customary route that uncle used always. Technology had not got that far to the steering wheel. This was followed by sustainability in packaging--Hassoun et al. (2024), Yakoubi (2024). More science, more futuristic discourse. Nice in terms of food quality, but once again, not answering the question of why cold-chain infrastructure in this area was still grappling with such fundamental issues as reliable supply of electricity and low-cost storage. Agriculture supply chains were directly mentioned by some of the studies. Mohit Malik et al. (2024) tested Industry 4.0 on Indian dairy. Good start. However even they did not go deep into the barrier of the farmer opinion or the environmental problems of Rajasthan such as the heatwaves that spoil the milk quality. Some other articles on the topic of circular economy such as Craparo et al. (2023), sounded cool (reuse, recycling, sustainability), but failed to discuss technological fear and financial accessibility issues.

3. Enablers, Attributes and criteria selection

Selecting the appropriate enablers, criteria, and attributes were actually one of the most significant steps of this research, since, unless we examine the appropriate things, we cannot expect appropriate insights, and this is why we did not simply list barriers randomly but, in fact, we explicitly attempted to get to know what exactly is stopping the digital transformation of the horticulture and dairy supply channels in Rajasthan, and why Industry 4.0 cannot jump onto actual ground conditions, and that is why, instead of just dropping the names of the obstacles, we made each of them talk to stakeholders, read a good Under Technology & Infrastructure Readiness (BRL1), the initial requirements was BRL11 Digital Infrastructure, since frankly speaking, the smart systems cannot do their jobs as the simple connectivity fails, this is why we mentioned Patchy internet connectivity (BRL111), Low IT device penetration (BRL112), Limited IoT/sensor uptake (BRL113), Lack of digital records (BRL114), No cloud monitoring support (BRL115), and Device interoperability problems (BRL116) which reflects the basic

The second criteria BRL12 was Automation and Smart Equipment due to the fact that the majority of grading and sorting is still being done manually and automation seems like a far-fetched dream, so we included Manual sorting/grading dominance (BRL121), Low automation of smart milking (BRL122), There are no predictive maintenance warning signs (BRL123),

Low robotics in packaging (BRL124), Weak cold-chain monitoring (BRL125), and There is No digital traceability (BRL1) Then it was followed by BRL13 Technology Skills & Training, since people should know technology usage, so we had Digital literacy gap (BRL131), Lack of technicians (BRL132), Weak training on Industry 4.0 (BRL133), Fear of job loss due to tech (BRL134), Language/interface barriers (BRL135), and Low confidence in data handling (BRL136); this also tells the level of human readiness. Next onto BRL2, Organizational and Human Readiness, it is here that we discovered that technology per se cannot make any difference and when it comes to real game-changing it is people and culture that do this, hence the initial criteria of BRL21 Change Management Culture included Traditional mindset (BRL211), Leaders not prioritizing technology (BRL212), Low awareness of digital benefits (BRL213), Delayed digital decisions (BRL214), Resistance to compliance digitization (BRL215), and Lack of innovation champions

Next on criteria BRL22 Workforce Motivation & Skills revealed the reason why transformations do not work when workers are not motivated or trained, which is why we added No tech-based incentives (BRL221), Limited upskilling programs (BRL222), Weak collaboration culture (BRL223), High labor turnover (BRL224), No tech-driven safety monitoring (BRL225) and Anxiety toward devices (BRL226) with an eye on actual human issues related to change. The third criteria under BRL2 was the BRL23 Supply Chain Coordination as everything is messy when there is lack of communication and coordination so we have chosen Weak farmer-processor communication (BRL231), Fragmented distribution chain (BRL232), Unstandardized quality data (BRL233), Conflicts in cooperative networks (BRL234), Pricing transparency issues (BRL235), and Seasonal workforce instability (BRL236), which are the big obstacles in everyday working. At last, BRL3 Policy, Market & Sustainability Readiness took its place since despite willing farmers and an effort by organizations, policies, economics and climatic realities could still play a big part hence under requirement BRL31 Market Competitiveness we placed Horticulture price fluctuations (BRL311), Middlemen dominating milk pricing (BRL312), Low export integration (BRL313), Poor demand forecasting (BRL314), Weak e-commerce participation (BRL315), and cold-chain unaffordable (BRL31)

Table 1 Enablers, criteria and Attributes selection

Enablers (BRLi4)	Criteria	Attributes	Code
BRL1 Technology & Infrastructure Readiness	BRL11 Digital Infrastructure	Patchy internet connectivity	BRL111
		Low IT device penetration	BRL112
		Limited IoT/sensor adoption	BRL113
		Lack of digital records	BRL114
		Low cloud monitoring usage	BRL115
		Device interoperability issues	BRL116
	BRL12 Automation & Smart Equipment	Manual sorting/grading dominance	BRL121
		Low smart milking automation	BRL122
		No predictive maintenance alerts	BRL123
		Low robotics in packaging	BRL124
		Weak cold-chain monitoring	BRL125
		No digital traceability	BRL126
	BRL13 Technology Skills & Training	Digital literacy gap	BRL131
		Lack of tech technicians	BRL132
		Weak training on Industry 4.0	BRL133
		Fear of job replacement	BRL134
		Interface language barriers	BRL135
		Low confidence in data handling	BRL136
BRL2 Organizational & Human Readiness	BRL21 Change Management Culture	Traditional mindset	BRL211
		Leaders not prioritizing tech	BRL212
		Low awareness of benefits	BRL213
		Delayed digital decisions	BRL214
		Resistance to compliance digitization	BRL215
		Lack of innovation champions	BRL216
	BRL22 Workforce Motivation & Skills	No tech-based incentives	BRL221
		Limited upskilling programs	BRL222
		Weak collaboration culture	BRL223
		High labor turnover	BRL224
		No tech-driven safety systems	BRL225
		Anxiety toward devices	BRL226
	BRL23 Supply Chain Coordination	Weak farmer–processor communication	BRL231
		Fragmented distribution chain	BRL232
		Unstandardized quality data	BRL233
		Conflicts in cooperative networks	BRL234
		Pricing transparency issues	BRL235
		Seasonal workforce instability	BRL236

Enablers (BRLi4)	Criteria	Attributes	Code
BRL3 Policy, Market & Sustainability Readiness	BRL31 Market Competitiveness	Horticulture price fluctuations	BRL311
		Milk price dominated by intermediaries	BRL312
		Low export market integration	BRL313
		Poor demand forecasting	BRL314
		Weak e-commerce participation	BRL315
		Cold-chain cost unaffordable	BRL316
	BRL32 Policy & Subsidy Access	Lack of subsidy awareness	BRL321
		Complicated compliance requirements	BRL322
		Delays in govt. tech support	BRL323
		Limited insurance for perishables	BRL324
		Certification challenges	BRL325
		Financial aid not accessible	BRL326
	BRL33 Environmental Sustainability	Water scarcity issues	BRL331
		Heat stress on produce/livestock	BRL332
		Spoilage due to poor storage	BRL333
		Waste not converted into by-products	BRL334
		Low renewable energy adoption	BRL335
		Poor feed/fertilizer analytics	BRL336
Total Enablers	Total Criteria	Total Attributes	
3	9	54	

The criteria BRL32 Policy and Subsidy Access revealed a lot of schemes do exist, but hardly anyone knows how to use them and so we have identified Lack of subsidy awareness (BRL321), Complicated compliance requirements (BRL322), Delay with govt. tech support (BRL323), Limited insurance perishables (BRL324), Certification challenges (BRL325) and Financial aid not available (BRL326), which are big systemic barriers. Finally, BRL33 Environmental Sustainability understood that Rajasthan is not a friendly climate and sustainability should be within our scope and we therefore from the selection of Water scarcity issues (BRL331), Heat stress on livestock/produce (BRL332), Spoilage due to poor storage (BRL333), Waste not utilized properly (BRL334), Low renewable energy adoption (BRL335), and Poor feed/fertilizer analytics (BRL336), since, these environmental factors are always in

the background. This last structure therefore has 3 Enablers, 9 Criteria and 54 Attributes and I must state that it just feels right, not too broad not too narrow but more than befitting around the actual problems being faced by Rajasthan in the Horticulture and dairy supply chain and at least more critically speaking, all of the attributes were either firsthand-experienced by stakeholders or well-articulated in literature, thus making this choice not only practical but also quite relevant in evaluating the Industry 4.0 readiness in the area.

4. Modeling Steps for Weak Attributes selection

Identifying the weak attributes that prevent the adoption of Industry 4.0 was not a random check list exercise, but rather a full and structured modeling process with clear steps that actually, performed in real-life situations, but not on the assumption of a model, which in this case is a selection of enablers, criteria, and attributes; the first stage (Step-I) was selection of enablers, criteria, and attributes because you cannot evaluate anything without defining the things you are looking at in the first place, we had three key enablers Technology and Infrastructure Readiness, Organizational and Human Read.

Table 2 Performance and Importance rating

Performance Rating			Importance Weighting		
Linguistic		Fuzzy	Linguistic		Fuzzy
Worst	W	(0,0.5,1.5)	Very Low	VL	(0,0.05,0.15)
Very Poor	VP	(1,2,3)	Low	L	(0.1,0.2,0.3)
Poor	P	(2,3.5,5)	Fairly Low	FL	(0.2,0.35,0.5)
Fair	F	(3,5,7)	Medium	M	(0.3,0.5,0.7)
Good	G	(5,6.5,8)	Fairy High	FH	(0.5,0.65,0.8)
Very Good	VG	(7,8,9)	High	H	(0.7,0.8,0.9)
Excellent	E	(8.5,9.5,10)	Very High	VH	(0.85,0.95,1.0)

The second step (Step-II) was to select a proper linguistic scale for performance rating and importance weighting because people express opinions with words, not numbers, so we translated subjective perceptions into structured linguistic variables like Good, Fair, Poor, Very Poor, Excellent, Very High, Medium, and so on, because a farmer isn't going to sit and say "my readiness level is exactly 0.78", they use phrases like "this is bad" or "we can't handle this right

now,” and fuzzy linguistic scales helped us respect that natural communication style while making it measurable.

In the third step (Step-III), we collected performance ratings and importance weight parameters from 100 stakeholders including farmers, dairy staff, logistics partners, agri-business actors, local leaders, etc., because they are the ones who live the issues every day, so they’re best equipped to judge how bad a barrier really is and how much importance it holds for Industry 4.0 readiness, and these judgments helped us see which barriers were slightly annoying and which ones were giant walls blocking the path; after gathering all those linguistic terms like “High”, “Low”, “Worst”, “Fair”, “Very Good”, in Step-IV we replaced every linguistic term with fuzzy numbers because computers don’t understand feelings and opinions — they work on numbers — so we converted these expressions into fuzzy triangular values like (0.3,0.5,0.7) for Medium or (1,2,3) for Very Poor, so now each opinion became a number but still held the original meaning behind it, keeping human feelings inside mathematical modeling which is a pretty cool combination;

Table 3 Importance of the attributes

Enablers (BRLi4)	Criteria	Attributes	IWCIi	IWCIj	IWCIjk	PRCIjk
BRL1 Technology & Infrastructure Readiness	BRL11 Digital Infrastructure	Patchy internet connectivity	H	M	H	P
		Low IT device penetration	H	M	M	F
		Limited IoT/sensor adoption	H	M	H	VP
		Lack of digital records	H	M	M	P
		Low cloud monitoring usage	H	M	M	W
		Device interoperability issues	H	M	H	F
	BRL12 Automation & Smart Equipment	Manual sorting/grading	H	H	H	VP
		Low smart milking automation	H	H	H	P

Enablers (BRLi4)	Criteria	Attributes	IWCli	IWClij	IWClijk	PRClijk
		No predictive maintenance alerts	H	H	VH	VP
		Low robotics in packaging	H	H	VH	W
		Weak cold-chain monitoring	H	H	VH	P
		No digital traceability	H	H	VH	VP
	BRL13 Technology Skills & Training	Digital literacy gap	H	VH	VH	VP
		Lack of tech technicians	H	VH	VH	VP
		Weak training programs	H	VH	H	VP
		Fear of job loss	H	VH	M	G
		Language interface barriers	H	VH	M	F
		Low data handling confidence	H	VH	H	P
BRL2 Organizational & Human Readiness	BRL21 Change Management Culture	Traditional mindset	VH	M	H	F
		Leaders not tech-focused	VH	M	H	VP
		Low awareness benefits	VH	M	VH	VP
		Delayed decisions	VH	M	VH	W
		Resistance to compliance digitization	VH	M	H	F
		No innovation champions	VH	M	H	P
	BRL22 Workforce Motivation & Skills	No tech-based incentives	VH	VH	VH	VP
		Limited upskilling programs	VH	VH	VH	VP
		Weak collaboration culture	VH	VH	H	F

Enablers (BRLi4)	Criteria	Attributes	IWCli	IWClij	IWClijk	PRClijk
		High labor turnover	VH	VH	H	P
		No digital safety monitoring	VH	VH	M	P
		Anxiety toward tech devices	VH	VH	H	P
	BRL23 Supply Chain Coordination	Weak communication	VH	VH	VH	P
		Fragmented chain	VH	VH	VH	W
		Unstandardized quality data	VH	VH	H	VP
		Coop conflicts	VH	VH	H	P
		Pricing transparency issues	VH	VH	H	F
		Seasonal workforce	VH	VH	M	F
BRL3 Policy, Market & Sustainability Readiness	BRL31 Market Competitiveness	Price fluctuations	M	VL	M	F
		Middlemen price control	M	VL	L	W
		Low export integration	M	VL	FL	VP
		Demand forecasting gap	M	VL	FL	F
		Weak e-commerce participation	M	VL	L	W
		High cold-chain cost	M	VL	M	P
	BRL32 Policy & Subsidy Access	Low subsidy awareness	H	H	VH	VP
		Complicated compliance	H	H	H	VP
		Govt. support delays	H	H	M	W
		Low perishable insurance	H	H	M	P
		Certification challenges	H	H	M	F
		Financial aid inaccessible	H	H	M	P

Enablers (BRLi4)	Criteria	Attributes	IWCli	IWClij	IWClijk	PRClijk
	BRL33 Environmental Sustainability	Water scarcity	L	FL	M	F
		Heat stress	L	FL	M	W
		Poor storage spoilage	L	FL	FL	P
		No waste valorization	L	FL	FL	VP
		Low renewables in cold chain	L	FL	L	P
		Poor feed optimization	L	FL	FL	F

Once those fuzzy numbers were ready, Step-V required us to aggregate fuzzy ratings for the enablers and criteria in the present industry, basically putting together the fuzzy performance scores and fuzzy importance weights to calculate a combined fuzzy score for each attribute, making it easier to see which barriers were light problems and which ones were seriously dragging the digital transformation backwards, and this combination process through fuzzy mathematical operations didn't just rank the barriers -- it balanced perception with impact, which gave realistic outcomes and avoided biased judgment from any single stakeholder group; finally, in Step-VI, we matched the aggregated fuzzy evaluation values (FBRLiCI) with predefined readiness

The whole modeling process of Step-I to Step-VI ensured that weak attributes were not selected from guesswork or random expert opinion but through a consistent and transparent scientific framework where every step verified the reliability and practicality of the selected barrier indicators, and with fuzzy methods allowing us to convert "soft" human perceptions into "hard" analytical results, the entire process thus became more trustworthy, as transformation in rural supply chains can't be dependent only on numbers nor only emotions -- it needs both things, mixed appropriately; Overall, these modeling steps helped to successfully identify the best 31 weak barriers that currently prevent the dairy and horticulture supply chains

5. Result and Discussion

After running the fuzzy-based evaluation and converting everyone's opinions into measurable readiness scores, the results showed a pretty clear picture: things aren't ready yet. Not even close in some cases. Out of the major 54 attributes we originally studied, 15 came out as the most critical weak points holding back Industry 4.0 adoption in Rajasthan's dairy and

horticulture supply chains. These 15 are basically the “big trouble topics” — the ones that need attention first if we want smart systems to work in real life. Let’s start with technology-related weaknesses because those stood out like a sore thumb. The worst among them was Low cloud monitoring usage (BRL115). Without cloud-based data systems, you can’t track temperature, quality, or location in real time, so problems like spoilage stay hidden until it’s too late. And adding to that, No robotics in packaging (BRL124) and Weak cold-chain monitoring (BRL125) also scored poorly. When fruits and milk don’t get proper temperature tracking, losses spike fast — something every farmer hates but has learned to accept. Manual sorting and grading dominance (BRL121) and Low smart milking automation (BRL122) were also quite weak, which shows that automation hasn’t really entered daily operations yet. It’s still a hands-on world — literally. And the worst part? No predictive maintenance alerts (BRL123) means machines break unexpectedly and cause huge interruptions. Basically, technology gaps are screaming for help.

Table 4 Weak attributes selected for the present study

Rank	Code	Weak Attribute (Barrier)	PR Category	Priority Level
1	BRL115	Low cloud monitoring usage	W	Critical
2	BRL124	Low robotics in packaging	W	Critical
3	BRL214	Delayed digital decision-making	W	Critical
4	BRL232	Fragmented distribution chain	W	Critical
5	BRL312	Middlemen controlling dairy pricing	W	Critical
6	BRL315	Weak e-commerce participation	W	Critical
7	BRL332	Heat stress impact on perishables	W	Critical
8	BRL121	Manual sorting/grading dominance	VP	High
9	BRL123	No predictive maintenance alerts	VP	High
10	BRL126	No digital traceability	VP	High
11	BRL131	Digital literacy gap	VP	High
12	BRL132	Lack of tech technicians	VP	High

Rank	Code	Weak Attribute (Barrier)	PR Category	Priority Level
13	BRL133	Weak training programs	VP	High
14	BRL212	Leaders not prioritizing technology	VP	High
15	BRL213	Low awareness of Industry 4.0 benefits	VP	High

But even if tech magically arrived tomorrow, would people be ready to use it? The results suggest... not really. The human and skill-related weaknesses paint a concerning picture. Digital literacy gap (BRL131), Lack of trained technicians (BRL132), and Weak training programs (BRL133) were consistently rated Very Poor. This means even if someone installs IoT sensors, there might be nobody around who knows how to operate or repair them. And Low confidence in data handling (BRL136) shows that the fear isn't just about using devices — it's about trusting digital information instead of "gut feeling" built over years. Technology anxiety is real, and it's slowing everything down.

Distribution of Weak Barriers by Rating Category

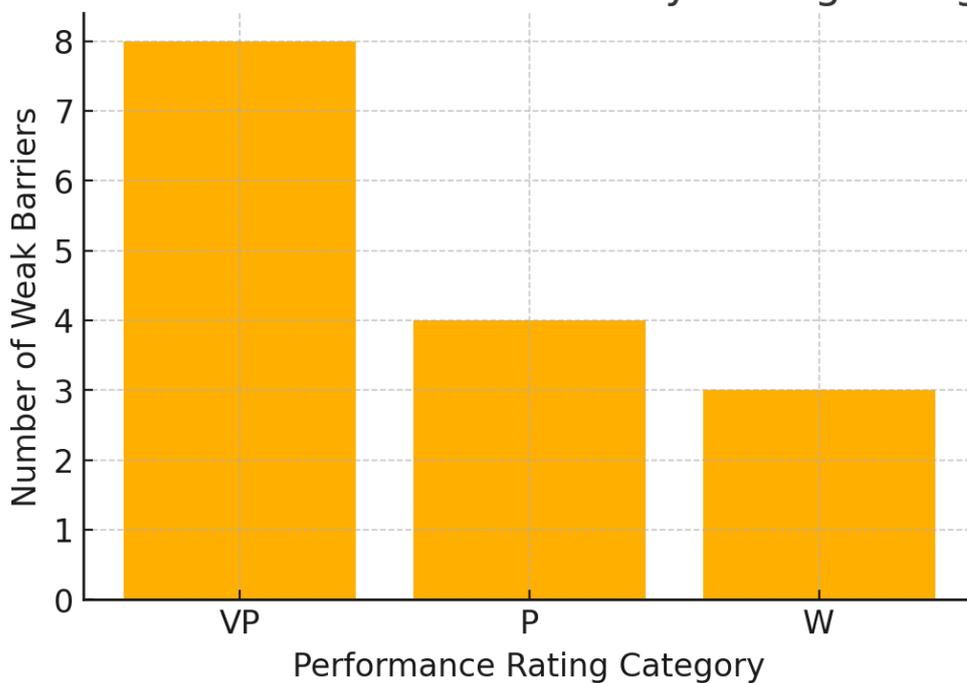


Figure 1 Performance rating of the weak attributes

However, maybe the most surprising finding was how organizational behaviour is dragging progress too. Leaders not prioritizing technology (BRL212) and Low awareness of Industry

4.0 benefits (BRL213) came out extremely weak. Leaders are supposed to drive innovation, but if they don't see the value, nothing moves. And Delayed digital decision-making (BRL214) makes it worse — decisions that should take weeks stretch into years. Another painful issue: No innovation champions (BRL216). Without someone pushing the change internally, most good ideas simply fade away. Workforce factors weren't much better. No tech-based incentives (BRL221) and Limited upskilling programs (BRL222) send a clear message: workers don't see what's in it for them. And when people don't feel rewarded or supported, their willingness to learn new tech drops. That leads to High labor turnover (BRL224) and Anxiety toward digital devices (BRL226) — nobody wants to feel replaceable or dumb in front of a machine. Moving toward market realities, the presence of Middlemen controlling dairy pricing (BRL312) still dominates the chain. Farmers can't negotiate better returns, so they don't feel motivated to upgrade into smart systems — why invest if you won't earn back? And Low export market integration (BRL313) shows that the region still isn't tapping into opportunities where tech is necessary for global quality standards. Plus, Weak e-commerce participation (BRL315) keeps farmers dependent on old selling systems. Tech-based market access is barely there.

6. Conclusion

The present study highlighted how the adoption of Industry 4.0 technologies in Rajasthan's dairy and horticulture supply chains remained far from adequate. Major readiness gaps persisted across technical infrastructure, workforce capability, leadership behavior, and policy accessibility. Many stakeholders continued to operate with limited automation, poor data usage, and almost no digital traceability. Barriers linked to digital literacy, skill shortages, and technology acceptance proved equally concerning. A number of decision-makers still showed hesitation toward investing in modern tools, resulting in delayed transformation efforts. Market-related issues such as dependence on middlemen and weak digital selling channels also created strong resistance to innovation. Environmental challenges, especially heat stress affecting perishables, further amplified the urgency for advanced monitoring solutions.

The present analysis demonstrated that fifteen core weak attributes demanded immediate attention, particularly cloud-based monitoring, predictive maintenance, robotics integration, strong digital awareness, and supply chain coordination. Strengthening these areas held significant potential to uplift productivity, reduce losses, and enhance value for farmers and consumers. Digital technology, however, could only deliver meaningful change when people and systems became genuinely ready to adopt it.

Recommendations framed through the findings suggested multiple strategic actions. First, infrastructure upgrades for reliable connectivity, affordable cold-chain monitoring, and cloud platforms should be prioritized. Second, regular digital skill training and hands-on technology demonstrations could build trust and confidence among users. Financial incentives and simplified compliance support would motivate investments in smart solutions. Encouraging leadership engagement and creating innovation champions in cooperatives would promote faster decision-making. Direct market access channels such as e-commerce should be strengthened to reduce pricing exploitation by intermediaries. Climate-responsive storage and monitoring technologies also needed urgent deployment considering Rajasthan's harsh weather conditions.

References

- [1] Abdul Jabbar, P., Akhtar, P., & Ali, S. I. (2024). The interplay between blockchain and big data analytics for enhancing supply chain value creation in micro, small, and medium enterprises. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10479-024-06415-5>
- [2] Xu, Q., & Dong, Y. (2024). How digital technology contributes to the low-carbon transformation of industries—a segmentation perspective based on three major industries. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10668-024-05868-9>
- [3] Gupta, M., Jauhar, S. K., Paul, S. K., & Pratap, S. (2024). Relation between digital innovation and industry 4.0: Existing themes and emerging research trends. Springer Science and Business Media LLC. <https://doi.org/10.1007/s12597-024-00865-y>
- [4] Rawat, U., Kumar, A., & Anbanandam, R. (2024). Evaluating the preparedness of freight logistics firms for cyber-physical systems integration: A SAP-LAP methodology for sustainable development. Springer Science and Business Media LLC, 26(1), 1–23. <https://doi.org/10.1007/s40171-024-00421-z>
- [5] Dai, S. (2024). Understanding automation's impact on ecological footprint: Theory and empirical evidence from Europe. Springer Science and Business Media LLC, 88(2), 503–532. <https://doi.org/10.1007/s10640-024-00938-y>
- [6] Raza, A., Kashif, U., Papiashvili, T., Erokhin, V., & Fadol, A. A. A. (2024). Hesitant fuzzy entropy analysis of financial literacy and micro-credit accessibility of Pakistani farmers:

A bankers' perspective. Springer Science and Business Media LLC.
<https://doi.org/10.1007/s13132-024-02385-y>

[7] Binfield, L., Nasir, V., & Dai, C. (2024). Bamboo industrialization in the era of Industry 5.0: An exploration of key concepts, synergies, and gaps. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10668-024-05584-4>

[8] Dasgupta, S. (2024). The political economy of care: A developmental perspective. Springer Science and Business Media LLC, 67(3), 615–636. <https://doi.org/10.1007/s41027-024-00520-6>

[9] Sirajudheen, P., Vigneshwaran, S., Thomas, N., Selvaraj, M., Assiri, M. A., & Park, C. M. (2024). Critical assessment of recent advancements in chitosan-functionalized iron and geopolymer-based adsorbents for the selective removal of arsenic from water. Springer Science and Business Media LLC, 196(10), 946. <https://doi.org/10.1007/s10661-024-13087-y>

[10] Borsano, P., Marozzo, V., Bonaglia, M., Di Minin, A., & Crupi, A. (2024). Digital transformation and digital dynamic capabilities improvement in the low-medium technology sector: Evidence from Thai family firms. Springer Science and Business Media LLC, 23(5), 683–712. <https://doi.org/10.1057/s41291-024-00281-6>

[11] Zhao, G., Ye, C., Dennehy, D., Liu, S., Harfouche, A., & Olan, F. (2024). Analysis of barriers to adopting Industry 4.0 to achieve agri-food supply chain sustainability: A group-based fuzzy analytic hierarchy process. *Business Strategy and the Environment*, 33(8), 8559–8586. <https://doi.org/10.1002/bse.3928>

[12] Sharma, V., Agrawal, R., & Manupati, V. K. (2024). Blockchain technology as an enabler for digital trust in supply chain: Evolution, issues and opportunities. Springer Science and Business Media LLC, 15(9), 4183–4209. <https://doi.org/10.1007/s13198-024-02471-z>

[13] Luo, X., & Huang, R. (2024). How to achieve sustainable development of a smart city: A comprehensive bibliometric analysis. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10098-024-02945-5>

[14] Barman, A., Chakraborty, A. K., Sana, S. S., & Banerjee, P. (2024). Pricing strategy and risk-averse flexibility in a sustainable supply chain: A dual-channel logistics process under reward contracts and demand uncertainty. Springer Science and Business Media LLC, 25(4), 733–762. <https://doi.org/10.1007/s40171-024-00407-x>

- [15] Zhen, Z., & Yao, Y. (2024). The confluence of digital twin and blockchain technologies in Industry 5.0: Transforming supply chain management for innovation and sustainability. Springer Science and Business Media LLC. <https://doi.org/10.1007/s13132-024-02151-0>
- [16] Silva, J. S., Oliveira, A. M., Oliveira, J. V., & Bouzon, M. (2024). Barriers to digital transformation in fruit and vegetable supply chains: A multicriteria analysis using ISM and MICMAC. Springer Science and Business Media LLC. <https://doi.org/10.1007/s12597-024-00809-6>
- [17] Mohammadi, M. J., Hosseinzadeh, M., & Salmanpour, S. (2024). The effect of flaxseed extract incorporated with nano ZnO and ZnO-Mg on the physicochemical, mechanical, and antioxidant properties of sago starch films. Springer Science and Business Media LLC, 18(8), 6803–6815. <https://doi.org/10.1007/s11694-024-02694-5>
- [18] Shi, Y., & Wei, F. (2024). Comparative analysis of digital economy-driven innovation development in China: An international perspective. Springer Science and Business Media LLC. <https://doi.org/10.1007/s13132-024-02128-z>
- [19] Hassoun, A., Aït-Kaddour, A., Dankar, I., Safarov, J., Ozogul, F., & Sultanova, S. (2024). The significance of Industry 4.0 technologies in enhancing various unit operations applied in the food sector: Focus on food drying. Springer Science and Business Media LLC, 18(1), 109–128. <https://doi.org/10.1007/s11947-024-03465-2>
- [20] Tajbakhsh, A., Nematollahi, M., & Zamenjani, A. S. (2024). Migration to the quadruple bottom line framework for achieving sustainable development goals: The 4Ps of sustainability. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10479-024-06042-0>
- [21] Yakoubi, S. (2024). Sustainable revolution: AI-driven enhancements for composite polymer processing and optimization in intelligent food packaging. Springer Science and Business Media LLC, 18(1), 82–107. <https://doi.org/10.1007/s11947-024-03449-2>
- [22] Ghodsian, N., Benfriha, K., Olabi, A., Gopinath, V., Talhi, E., Hof, L., & Arnou, A. (2024). MSOA: A modular service-oriented architecture to integrate mobile manipulators as cyber-physical systems. Springer Science and Business Media LLC. <https://doi.org/10.1007/s10845-024-02404-4>

- [23] Zong, Z., & Guan, Y. (2024). AI-driven intelligent data analytics and predictive analysis in Industry 4.0: Transforming knowledge, innovation, and efficiency. Springer Science and Business Media LLC. <https://doi.org/10.1007/s13132-024-02001-z>
- [24] Singh, S., Lakshay, & Jauhar, S. K. (2024). Unveiling barriers to IoT adoption in the maritime freight industry. Springer Science and Business Media LLC. <https://doi.org/10.1007/s13198-024-02342-7>
- [25] Mishra, D., Mohapatra, B., Satpathy, A. S., Muduli, K., Mishra, B., Mishra, S., & Paliwal, U. (2024). The pandemic COVID-19 and associated challenges with implementation of artificial intelligence (AI) in Indian agriculture. Springer Science and Business Media LLC, 15(6), 2715–2729. <https://doi.org/10.1007/s13198-024-02293-z>
- [26] Wang, Z.-J., Sun, Y., Su, Q., Deveci, M., Govindan, K., Skibniewski, M. J., & Chen, Z.-S. (2024). Smart contract application in resisting extreme weather risks for the prefabricated construction supply chain: Prototype exploration and assessment. *Group Decision and Negotiation*, 33(5), 1049–1087. <https://doi.org/10.1007/s10726-024-09877-x>
- [27] Panigrahi, S. S., Mishra, S., & Sahu, B. (2024). What hinders the green supply chain management adoption in the Indian aluminium sector? *Environment, Development and Sustainability*. <https://doi.org/10.1007/s10668-024-04468-x>
- [28] Dubey, R., Bryde, D. J., & Foropon, C. (2024). Design and management of humanitarian supply chains for pandemics: Lessons from COVID-19. *Annals of Operations Research*, 335(3), 885–898. <https://doi.org/10.1007/s10479-024-05944-3>
- [29] Masinga, P., Simbanegavi, T. T., Makuvara, Z., Marumure, J., Chaukura, N., & Gwenzi, W. (2024). Emerging organic contaminants in the soil-plant-receptor continuum: Transport, fate, health risks, and removal mechanisms. *Environmental Monitoring and Assessment*, 196(4), 367. <https://doi.org/10.1007/s10661-023-12282-7>
- [30] Malik, M., Gahlawat, V. K., Mor, R. S., & Hosseinian-Far, A. (2024). Towards white revolution 2.0: Challenges and opportunities for the industry 4.0 technologies in Indian dairy industry. *Operations Management Research*. <https://doi.org/10.1007/s12063-024-00482-4>
- [31] Wong, W. P., Anwar, M. F., & Soh, K. L. (2024). Transportation 4.0 in supply chain management: State-of-the-art and future directions towards 5.0 in the transportation sector.

Operations Management Research, 17(2), 683–710. <https://doi.org/10.1007/s12063-024-00471-7>

[32] Elaine, E., Bhandari, B., Tan, C. P., & Nyam, K. L. (2024). Recent advances in the formation, stability, and emerging food application of water-in-oil-in-water double emulsion carriers. Food and Bioprocess Technology, 17(11), 3440–3460. <https://doi.org/10.1007/s11947-024-03350-y>

[33] Chen, M., & Long, Y. (2024). Empowering rural revitalization: Unleashing the potential of e-commerce for sustainable industrial integration. Journal of the Knowledge Economy, 15(4), 18813–18831. <https://doi.org/10.1007/s13132-024-01813-3>

[34] Serrano-Ruiz, J. C., Ferreira, J., Jardim-Goncalves, R., & Ortiz, Á. (2024). Relational network of innovation ecosystems generated by digital innovation hubs: A conceptual framework for the interaction processes of DIHs from the perspective of collaboration within and between their relationship levels. Journal of Intelligent Manufacturing, 36(3), 1505–1545. <https://doi.org/10.1007/s10845-024-02322-5>

[35] Chanchaichujit, J., Balasubramanian, S., & Shukla, V. (2024). Barriers to Industry 4.0 technology adoption in agricultural supply chains: A Fuzzy Delphi-ISM approach. International Journal of Quality & Reliability Management, 41(7), 1942–1978. <https://doi.org/10.1108/ijqrm-07-2023-0222>