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An Integrated Decision-Support Platform for Agricultural Equipment Sharing: Multi-Criteria Recommendation, Booking and Utilisation Analytics

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Abstract: ***Access to suitable agricultural machinery at the required time remains a practical challenge for farmers who cannot economically justify individual ownership of expensive equipment. Equipment-sharing and custom-hiring arrangements can improve access, but their effectiveness depends on the ability to identify suitable machinery, verify availability, coordinate bookings and understand equipment demand. This paper presents KrishiYantra, an integrated web-based decision-support platform designed to support agricultural equipment sharing through multi-criteria recommendation, date-based booking, cooperative cost allocation and equipment utilisation analytics. The platform is implemented using Java, Spring Boot, Spring MVC, Spring Data JPA, Spring Security, Thymeleaf and MySQL. Its recommendation mechanism ranks eligible equipment using operation compatibility, land suitability, budget headroom, availability, owner rating and geographical distance. Booking requests undergo date-overlap validation and availability revalidation before submission. A cooperative booking feature distributes the estimated rental cost equally among participating members. Booking records are further used to calculate equipment utilisation and demand-related indicators. The system also incorporates weather advisories and basic usage-threshold maintenance indicators. Functional evidence was examined using archived automated test reports containing 105 test cases, with no recorded failures, errors or skipped tests. Synthetic examples are used to illustrate recommendation scoring, booking conflict detection, cooperative cost allocation and utilisation calculations. The results demonstrate the functional integration of these modules, while field usability, real-world economic impact, scalability and operational performance remain subjects for future evaluation.***

Keywords: Agricultural equipment sharing, custom hiring, decision-support system, multi-criteria recommendation, equipment booking, utilisation analytics, cooperative rental.

I. INTRODUCTION

Agriculture continues to depend on timely access to machinery for operations such as land preparation, sowing, spraying, harvesting and post-harvest processing. Mechanisation can reduce dependence on manual labour and improve the efficiency of agricultural operations. However, purchasing and maintaining agricultural machinery can involve substantial capital expenditure. This creates difficulties for farmers whose landholdings or frequency of machinery use do not justify individual ownership.

Custom Hiring Centres (CHCs), equipment rental arrangements and farmer-to-farmer sharing models provide alternative ways of accessing machinery. These arrangements allow farmers to use equipment when required without bearing the entire cost of ownership. Research on agricultural equipment-sharing models has examined digital marketplaces, machinery rental, custom hiring and decision-support mechanisms [1]–[3]. Studies have also documented the opportunities and operational constraints associated with custom hiring services [10]–[18].

Despite the availability of rental and sharing models, selecting suitable machinery is not a simple process. A farmer may need to consider the type of agricultural operation, land area, equipment capacity, rental duration, budget, availability and distance from the equipment owner. Selecting machinery based only on its category or rental price may not provide an appropriate match.

Digital platforms can support this process by organising equipment listings, matching farmer requirements with available machinery and managing booking information. However, a platform that only displays listings may not adequately support the complete decision-making process. Recommendation, booking validation, cooperative access and utilisation information can provide complementary capabilities.

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This paper presents KrishiYantra, a web-based agricultural equipment-sharing and decision-support application. The platform integrates four principal capabilities:

1) Farmer-oriented multi-criteria equipment recommendation.
2) Date-based equipment booking with availability revalidation.
3) Cooperative booking with equal member cost allocation.
4) Booking-derived equipment utilisation and demand analytics.

Additional capabilities include role-based access, payment integration, equipment reviews, weather advisories and basic usage-threshold maintenance indicators.

The objective of this research is to describe the design, implementation and functional evaluation of the integrated platform. The study focuses on how these modules work together rather than claiming that equipment rental platforms or multi-criteria recommendation are individually new research concepts.

A. Problem Statement

Farmers seeking agricultural machinery through rental or sharing arrangements may encounter several interconnected problems:

- Difficulty identifying equipment compatible with a specific agricultural operation.
- Limited information for comparing equipment against land area, budget and distance.
- Uncertainty regarding whether equipment is already booked for the requested dates.
- Difficulty coordinating rental expenses among multiple farmers.
- Limited visibility into equipment booking frequency and utilisation patterns.
- Fragmented information across equipment listings, booking records and operational summaries.

A system that integrates these functions can provide structured support for equipment discovery, rental coordination and administrative monitoring.

B. Research Objectives

The objectives of KrishiYantra are:

1) To develop a web-based platform connecting farmers, equipment owners and administrators.
2) To implement a multi-criteria recommendation mechanism for ranking eligible agricultural equipment.
3) To provide date-based booking and prevent overlapping reservations for the same equipment.
4) To support cooperative equipment booking through equal allocation of estimated rental costs.
5) To derive equipment utilisation and demand indicators from booking records.
6) To integrate supporting features such as payment processing, weather advisories and basic maintenance indicators.
7) To evaluate the functional behaviour of the implemented modules using available automated test evidence and controlled examples.

C. Research Questions

The study is guided by the following research questions:

1) RQ1: How can multiple farmer-specific requirements be combined to rank eligible agricultural equipment?
2) RQ2: How can recommendation and date-based booking validation be integrated into a single workflow?
3) RQ3: How can booking records be transformed into equipment utilisation and demand indicators?
4) RQ4: How can cooperative booking support shared access through transparent cost allocation?
5) RQ5: What functional capabilities and limitations are observed in the integrated implementation?

D. Scope of the Study

The study covers the design and implementation of a web application and its core business logic. It evaluates the recommendation mechanism, booking rules, cooperative cost calculation and booking-derived analytics through source-code inspection, archived automated test reports and illustrative calculations.

The study does not claim field deployment, measured farmer adoption, increased crop yield, reduced operating costs, predictive maintenance accuracy or production-scale performance. These require separate empirical evaluation.

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II. RELATED WORK

A. Agricultural Equipment Sharing and Custom Hiring

Agricultural equipment sharing has been explored as a way to improve access to machinery without requiring every farmer to purchase equipment individually. Sengupta et al. examined a digitised access-based model for farm mechanisation through the Gold Farm platform [1]. Rakhra et al. proposed a smart equipment-renting and sharing model incorporating recommendation and decision-support techniques [2]. Hou et al. studied agricultural machinery rental optimisation using a dynamic artificial bee-ant colony algorithm [3]. These studies establish that digital sharing, rental coordination and optimisation are relevant research directions in agricultural mechanisation. They also demonstrate that the use of computational techniques for equipment selection and allocation is not itself a new concept. Research on custom hiring centres has examined their role in agricultural mechanisation and the opportunities and constraints associated with their operation [10], [13], [14], [15]. Studies conducted in different Indian regions have also examined farmer satisfaction, service utilisation, institutional models and economic aspects of custom hiring [11], [12], [16]–[19]. The reviewed work highlights that equipment access involves more than the existence of a rental marketplace. Service availability, location, affordability, demand patterns and operational coordination also influence the usefulness of such arrangements.

B. Multi-Criteria Machinery Selection

Agricultural machinery selection is a multi-attribute decision problem. Equipment may differ in capacity, suitability, operating cost, efficiency and other technical characteristics. García-Alcaraz et al. investigated a hybrid multi-attribute approach for agricultural tractor selection [4]. Durczak et al. presented a computer-based system supporting agricultural machinery and farm tractor purchase decisions [5]. Lu et al. examined agricultural machinery selection using an improved CRITIC-Entropy and GRA-TOPSIS approach [6]. Puška et al. studied multi-criteria methods for evaluating agricultural machinery [7]. More recent work has explored the integration of machine learning and multi-criteria decision-making for sustainable tractor selection [8]. These studies demonstrate the relevance of combining several attributes when comparing machinery. KrishiYantra applies this general principle to equipment rental matching. Instead of selecting machinery for purchase, the platform ranks eligible rental listings according to farmer requirements, including operation compatibility, land suitability, budget headroom, availability, owner rating and distance.

C. Digital Platforms and Operational Monitoring

Digital agricultural platforms increasingly incorporate equipment listings, booking workflows, geolocation and operational information. Recent research has examined cooperative agricultural machinery operations and information systems for evaluating machinery-sharing efficiency [9], [20]. A web-based equipment rental system for sustainable farming has also been described in recent literature [21]. Work on real-time monitoring in custom hiring centres highlights the importance of operational visibility and information availability [22]. Recent platform-oriented studies have additionally explored cloud-based agricultural equipment rental and integrated agricultural marketplaces [25], [26]. These developments indicate that digital equipment rental systems are an active area of research. KrishiYantra focuses on the integration of farmer-specific ranking, date-conflict-aware booking, cooperative cost allocation and booking-derived utilisation analytics within a single application.

D. Research Gap

The reviewed literature demonstrates that agricultural equipment sharing, custom hiring, machinery selection and digital rental platforms have each received research attention. Existing systems have explored machine-learning-based recommendations, cloud-based equipment rental, geolocation, booking management and digital monitoring. Consequently, the present study does not claim that agricultural equipment rental platforms or multi-criteria machinery selection are individually novel.

Instead, KrishiYantra focuses on integrating several complementary capabilities within a single implemented web application:

1) Farmer-oriented multi-criteria equipment recommendation.
2) Date-based booking with availability revalidation.
3) Cooperative booking with equal member cost allocation.
4) Booking-derived equipment utilisation and demand analytics.

The study contributes a system-level implementation and functional evaluation of these integrated capabilities. Its current evaluation is based on source-code inspection, archived automated test reports and controlled synthetic calculations rather than field trials or measured farmer outcomes.

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III. PROPOSED SYSTEM AND METHODOLOGY

A. Research Approach

The study follows a design-and-development approach. The application was examined to identify its architecture, business logic, recommendation mechanism, booking rules and analytics calculations.

The methodology consists of the following stages:

1) Identification of equipment-sharing requirements.
2) Design of a role-based web application.
3) Implementation of equipment recommendation and booking workflows.
4) Integration of cooperative booking and analytics.
5) Examination of supporting modules.
6) Functional evaluation using available test reports and illustrative scenarios.
7) Identification of implementation limitations and future research directions.

The research evaluates the application as a software artefact. It does not use a farmer survey or a live operational dataset.

B. System Architecture

KrishiYantra follows a layered web application architecture based on the Model-View-Controller (MVC) pattern.

The presentation layer uses Thymeleaf templates to display user interfaces. Spring MVC controllers receive user requests and coordinate application operations. Service classes implement recommendation, booking, analytics and related business rules. Spring Data JPA repositories provide database access, while MySQL stores application data. Spring Security provides authentication and role-based access control. External integrations support payment processing and weather information.

The architecture can be represented as:

1) Presentation layer: Thymeleaf user interfaces.
2) Controller layer: Spring MVC request handling.
3) Service layer: Recommendation, booking, cooperative booking, analytics, payment and weather logic.
4) Repository layer: Spring Data JPA data access.
5) Database layer: MySQL.
6) External services: Razorpay payment gateway and weather API providers.

C. User Roles

The application supports three principal roles.

1) Farmer: A farmer can explore equipment listings, provide rental requirements, receive recommendations, submit booking requests, participate in cooperative bookings, make payments and submit reviews.
2) Equipment Owner: An equipment owner can manage equipment listings and view booking-related information associated with their equipment.
3) Administrator: The administrator has access to administrative functions and platform-level information, subject to the implemented role restrictions.

Role-based access helps separate user responsibilities and restrict access to protected application functions.

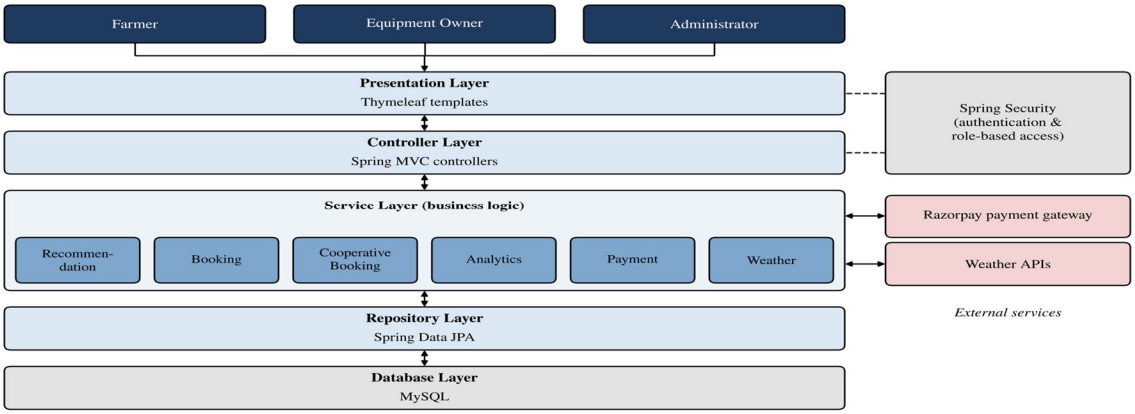

Fig. 1 Proposed system architecture

D. Database Design

The application uses MySQL with seven principal entity classes:

TABLE I
PRINCIPAL DATABASE ENTITIES

Entity	Purpose
User	Stores user and role-related information
Equipment	Stores equipment listing details
Booking	Stores rental requests and booking status
CooperativeGroup	Stores cooperative booking information
Payment	Stores payment-related records
Review	Stores equipment reviews and ratings
PasswordResetToken	Supports password-reset functionality

The entity structure supports the core rental workflow and the related platform features.

E. Multi-Criteria Equipment Recommendation

The recommendation mechanism is designed to rank eligible equipment according to the requirements entered by a farmer. The system considers six criteria:

1) Operation compatibility.
2) Land suitability.
3) Budget headroom.
4) Availability.
5) Owner rating.
6) Geographical distance.

The criteria are assigned the following weights.

TABLE II
RECOMMENDATION CRITERIA AND WEIGHTS

Criterion	**Weight**
Operation compatibility	30%
Land suitability	20%
Budget headroom	20%
Availability	15%
Owner rating	10%
Geographical distance	5%
Total	**100%**

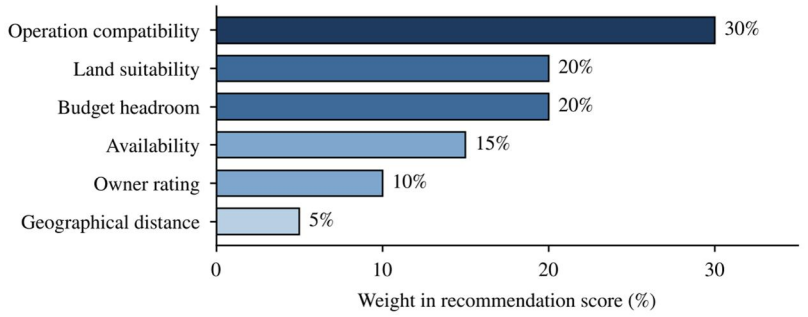

Fig. 2 Recommendation criteria weight distribution (30%, 20%, 20%, 15%, 10%, 5%)

The weighted recommendation score for equipment *j* is:

$$R_j = \frac{\sum_{i \in C_j} w_i s_{ij}}{\sum_{i \in C_j} w_i} \quad (1)$$

where:

- R_j represents the normalised recommendation score of equipment *j*.
- w_i represents the weight assigned to criterion *i*.
- s_{ij} represents the normalised score of equipment *j* for criterion *i*.
- C_j represents the set of criteria for which valid data are available.

The score is multiplied by 100 when displayed as a percentage.

1) *Operation Compatibility:* Operation compatibility evaluates whether the equipment supports the agricultural operation selected by the farmer.

The implemented scoring assigns:

- Primary operation match: 1.0.
- Secondary operation match: 0.6.

Equipment that does not satisfy the required operation is excluded through eligibility filtering.

2) *Land Suitability:* Land suitability considers the equipment's coverage capacity, requested rental duration and farmer's land area.

$$S_{land} = min\left(1, \frac{Coverage\ per\ day \times Rental\ days}{Land\ area}\right) \quad (2)$$

The score is capped at 1.0.

3) *Budget Headroom:* The budget criterion represents the remaining budget capacity after considering the estimated rental cost.

$$S_{budget} = max\left(0, min\left(1, \frac{B - E}{B}\right)\right) \quad (3)$$

where *B* is the farmer's stated budget and *E* is the estimated rental cost.

This score is a budget-headroom measure, not a direct affordability score. Equipment exceeding the budget is excluded through the eligibility rules.

4) *Availability:* Availability is checked against existing booking dates. Equipment that conflicts with the requested rental period is excluded.

For eligible candidates, the availability criterion receives a score of 1.0. Consequently, availability acts primarily as a hard eligibility filter rather than differentiating the scores of candidates that have already passed the filter.

5) *Owner Rating:* The owner-rating score is calculated using the average equipment rating.

$$S_{rating} = \frac{Average\ rating}{5} \quad (4)$$

The score is normalised to the range from 0 to 1.

6) *Geographical Distance:* The distance score is calculated using geographical coordinates and the Haversine distance.

$$S_{distance} = 1 - min\left(1, \frac{d}{D_{max}}\right) \quad (5)$$

where:

- *d* is the calculated distance in kilometres.
- D_{max} is the normalisation distance of 500 km.

The Haversine calculation uses an Earth radius of 6371.0088 km.

7) *Missing Data and Eligibility:* When a criterion does not have valid data, it is omitted from the candidate's weighted score and the remaining weights are renormalised.

Operation compatibility, budget and availability are treated as eligibility conditions. The candidate pool is limited to a maximum of 500 equipment records, and the returned recommendation list is capped at a maximum of 10 results.

The recommendation request duration is limited to 60 days in the recommendation workflow.
The workflow is:

1) Receive farmer requirements.
2) Retrieve potential equipment candidates.
3) Apply operation, budget and availability filters.
4) Calculate individual criterion scores.
5) Renormalise weights for available criterion data.
6) Calculate the final recommendation score.
7) Sort eligible candidates.
8) Return up to 10 recommendations.

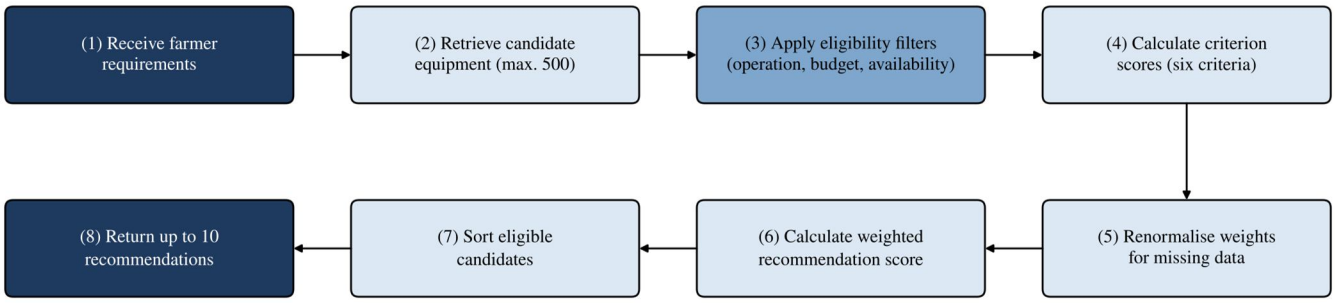

Fig. 3 Recommendation workflow

F. *Equipment Booking and Conflict Validation*

The booking module enables farmers to request equipment for a specified date range.
The system uses an inclusive date-range approach. If a requested booking starts on date S_r and ends on date E_r, it conflicts with an existing booking starting on S_e and ending on E_e when:

$$S_e \leq E_r \quad AND \quad E_e \geq S_r \tag{6}$$

Cancelled and rejected bookings do not block equipment availability.
The estimated rental amount is calculated as:

$$C = P \times D \tag{7}$$

where:

- C is the estimated rental cost.
- P is the daily rental price.
- D is the inclusive number of rental days.

The booking service revalidates availability when the booking request is submitted. This is important because equipment availability may change after the recommendation list is generated.
The booking service permits a maximum rental duration of 90 days.

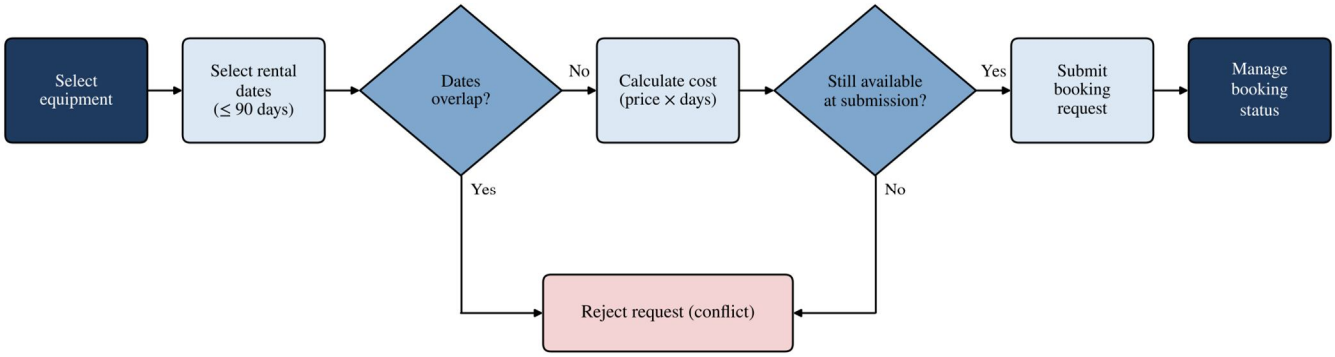

Fig. 4 Booking workflow

The workflow consists of equipment selection, date selection, conflict validation, cost calculation, booking submission and subsequent booking-status management.

G. Cooperative Booking and Cost Allocation

The cooperative booking module supports a group of farmers sharing an equipment rental request.

The estimated total rental amount is divided equally among all group members, including the farmer who initiates the booking.

$$C_m = \frac{C_t}{N} \tag{8}$$

where:

- C_m is the estimated cost allocated per member.
- C_t is the total estimated rental cost.
- N is the total number of group members.

This feature provides a transparent cost-allocation calculation for cooperative equipment access.

The implementation supports equal cost allocation. It should not be interpreted as evidence that all group members have completed payment or that a complete inter-member settlement mechanism is available.

H. Equipment Utilisation and Demand Analytics

The analytics module uses booking records to provide equipment-level and platform-level information.

The implemented analytics include:

- Booking counts and booking statuses.
- Most-booked and least-booked equipment.
- Equipment without bookings.
- Equipment category distribution.
- Revenue summaries.
- Monthly booking trends.
- Average bookings per equipment.
- Booking-based utilisation.
- Gini coefficient for booking distribution.

The utilisation calculation is based on confirmed and completed booking records.

$$U = \frac{D_b}{D_a} \times 100 \tag{9}$$

where:

- U is the utilisation percentage.
- D_b is the number of unique booked days.
- D_a is the number of eligible available days in the reporting period.

Overlapping booking days are merged before calculating the number of unique booked days. The denominator begins from the later of the reporting-period start date or the equipment listing date.

Maintenance downtime is not excluded from the denominator. Therefore, this metric represents booking-based utilisation rather than actual machine operating hours.

Booking-frequency summaries and utilisation use different status and date rules. Booking-frequency summaries exclude cancelled and rejected bookings and filter using booking start dates. Utilisation uses confirmed and completed bookings and considers overlap with the reporting period.

1) *Gini Coefficient:* The Gini coefficient is used to describe the distribution of booking counts across equipment.

$$G = \frac{2\sum_{i=1}^{n} i x_i}{n\sum_{i=1}^{n} x_i} - \frac{n+1}{n} \tag{10}$$

where:

- n is the number of equipment items.
- x_i is the sorted booking count for item i, in ascending order.

The coefficient is undefined when there are no equipment items or when the total booking count is zero.

The Gini coefficient provides a measure of booking concentration. It does not directly measure physical productivity or machine operating efficiency.

I. *Weather Advisory*

The application integrates weather information through external weather services. Open-Meteo is used as a weather data source, with OpenWeatherMap available as a fallback provider.

The weather module can provide an advisory associated with the booking start date. Rain or storm conditions and a precipitation probability exceeding 60% can trigger a warning.

The advisory is informational. It does not automatically change the recommendation score, cancel a booking or reschedule agricultural operations.

J. *Basic Maintenance Indicators*

The application contains basic usage-threshold maintenance indicators. The implementation includes a maintenance-hours limit, current hours used and a maintenance-related status.

A warning threshold is defined at 90% of the configured usage limit.

These indicators are intended to provide basic maintenance awareness. The current implementation does not contain a complete maintenance-record entity, service-history repository, maintenance scheduling workflow, predictive-maintenance model or automated maintenance completion and reset process.

Accordingly, this module is described as a basic rule-based maintenance indicator rather than a predictive maintenance system.

K. *Payment and Review Features*

The application integrates Razorpay for payment processing and includes equipment review functionality.

Payment-related records are used by the analytics module for revenue summaries. Revenue calculations are based on successful payment records and their associated timestamps.

The availability of payment integration does not, by itself, establish the completion of every cooperative member's payment or the existence of a complete group settlement mechanism.

IV. IMPLEMENTATION AND FUNCTIONAL EVALUATION

A. *Technology Stack*

The application is implemented using the following technologies.

TABLE III
TECHNOLOGY STACK

Layer / Function	Technology
Programming language	Java
Application framework	Spring Boot 3.2.0
Web framework	Spring MVC
Presentation layer	Thymeleaf
Persistence	Spring Data JPA
Database	MySQL
Security	Spring Security
External payment service	Razorpay
Weather integration	Open-Meteo with OpenWeatherMap fallback
Build configuration	Maven

The architecture separates presentation, request handling, business logic and persistence responsibilities. This supports modular implementation of the application's principal workflows.

B. *Functional Evaluation Method*

The evaluation was performed by examining the implemented source code, available automated test reports and controlled illustrative scenarios.

The archived test reports contained 105 test cases across recommendation, analytics, utilisation, booking, query, request-validation and controller-security modules.

The archived reports recorded zero failures, zero errors and zero skipped tests. These reports are evidence of the recorded test execution represented in the supplied project archive. They were not freshly rerun as part of the present evaluation.

TABLE IV
SUMMARY OF ARCHIVED AUTOMATED TEST EVIDENCE

Test Module	Test Cases
RecommendationScoringServiceTest	19
RecommendationServiceTest	16
AnalyticsServiceTest	18
UtilizationCalculatorTest	9
BookingServiceRevalidationTest	2
RecommendationQueriesTest	8
RecommendationRequestDTOTest	7
AnalyticsPeriodTest	7
RecommendationControllerSecurityTest	8
AnalyticsControllerSecurityTest	11
Total	**105**

Archived report summary: 105 recorded tests, 0 failures, 0 errors and 0 skipped tests.
The recommendation tests cover operation matching, eligibility conditions, scoring, land suitability, budget headroom, rating, missing coordinates, Haversine distance, normalisation, explanations and score bounds.
The utilisation tests cover inclusive date calculations, overlapping bookings, adjacent periods, reporting-period clipping, listing dates, zero denominators and Gini calculations.
The analytics tests cover booking statuses, monthly trends, utilisation, successful payment records and role-related data access.
Booking tests include availability revalidation. Controller security tests examine role restrictions for recommendation and analytics endpoints.

C. Synthetic Recommendation Example

A controlled example was used to illustrate how the recommendation formula ranks eligible equipment.
The following scores are illustrative synthetic values and are not results from actual farmer transactions.

TABLE V
ILLUSTRATIVE RECOMMENDATION RESULTS

Equipment	Recommendation Score
Equipment A	78.50%
Equipment B	73.00%
Equipment C	87.69%

Equipment C receives the highest illustrative score. Its land-suitability, rating and distance data are unavailable in the example; the corresponding weights are omitted and the remaining criterion weights are renormalised.
This example illustrates how the recommendation mechanism can handle incomplete criterion data without assigning an arbitrary zero to every missing value.
It does not establish that Equipment C would be the best choice in a real agricultural setting. Actual ranking depends on the accuracy of equipment data and the farmer's requirements.

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D. Synthetic Booking Conflict Example

The booking conflict rule was illustrated using three date ranges.

TABLE VI
ILLUSTRATIVE BOOKING CONFLICT VALIDATION

Existing Booking	Requested Booking	Result
10–14 May	14–17 May	Conflict
10–14 May	15–17 May	No conflict
10–14 May	12–13 May	Conflict

The first and third cases overlap with the existing booking and should be rejected as conflicting requests. The second case begins after the existing booking ends and is therefore non-conflicting under the implemented date-range rule.

This example demonstrates the importance of inclusive date comparison in equipment rental scheduling.

E. Synthetic Cooperative Cost Allocation

The cooperative cost-allocation formula was illustrated using a total estimated rental cost of ₹4,000 and five group members.

$$C_m = \frac{4000}{5} = ₹800$$

Each member is allocated an estimated share of ₹800.

This is an illustration of the implemented equal-allocation calculation. It does not represent a verified transaction or completed payment by five farmers.

F. Synthetic Utilisation Example

A synthetic 30-day reporting period was used to illustrate booking-day aggregation.

Consider three confirmed or completed booking periods:

- Booking 1: 5–9 May.
- Booking 2: 8–12 May.
- Booking 3: 20–22 May.

The first two booking periods overlap. Their unique booked days are therefore counted as 5–12 May, giving eight unique days. The third booking contributes three additional days.

Total unique booked days:

$$D_b = 8 + 3 = 11$$

Assuming 30 eligible available days:

$$U = \frac{11}{30} \times 100 = 36.67\%$$

The illustrative booking-based utilisation is 36.67%.

This example demonstrates overlap merging. It is not a measured utilisation result from a live equipment-sharing operation.

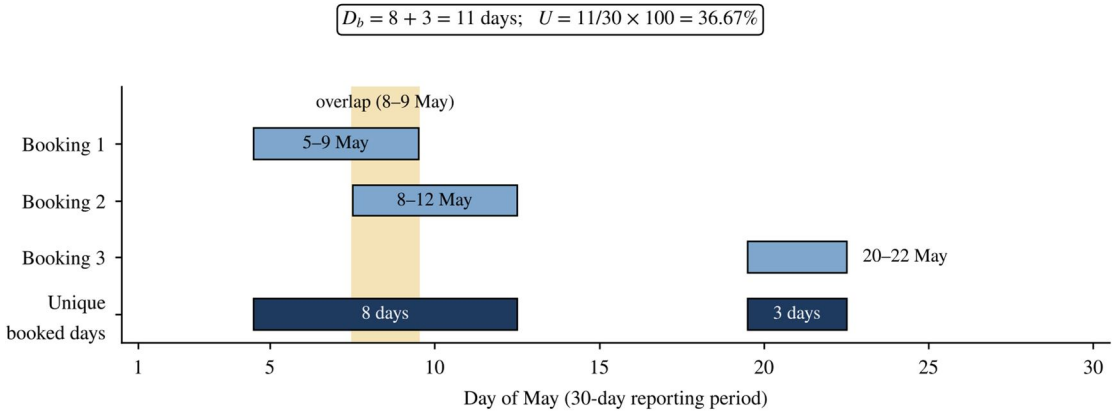

Fig. 5 Synthetic booking timeline illustrating overlapping dates and utilisation calculation

G. Illustrative Booking Distribution

An additional synthetic example was used to illustrate booking concentration.

For four equipment items with booking counts of 0, 1, 3 and 6, the Gini coefficient is:

$$G = \frac{2(1\times0 + 2\times1 + 3\times3 + 4\times6)}{4(0+1+3+6)} - \frac{5}{4}$$

$$G = \frac{38}{40} - 1.25 = -0.30$$

The negative value indicates that the values were substituted into the formula using the wrong ordering for the stated formula. For ascending booking counts, the correct numerator is:

$$2(1 \times 0 + 2 \times 1 + 3 \times 3 + 4 \times 6) = 76$$

Thus:

$$G = \frac{76}{40} - 1.25 = 0.65$$

The illustrative Gini coefficient is 0.65, indicating a concentrated distribution of bookings in this synthetic example.

This calculation is included to demonstrate the metric. It should not be confused with a measured platform result.

H. Results and Discussion

The functional evaluation indicates that the application contains an integrated workflow for equipment discovery, recommendation, booking and operational analytics. The recommendation mechanism combines multiple farmer-specific criteria and applies eligibility filters before ranking candidates. The use of hard filters for operation compatibility, budget and availability helps prevent clearly unsuitable equipment from being included in the ranked list. The weighted score then provides a relative ranking among eligible candidates. The booking module extends the recommendation workflow by revalidating availability at submission time. This is important because recommendation results may become outdated if another booking is submitted before the farmer confirms a request. The cooperative booking module introduces a shared-access mechanism through equal cost allocation. Its current contribution is the allocation calculation and group booking support, rather than a complete financial settlement workflow.

The analytics module transforms booking records into summaries that can support administrative monitoring. Booking counts and booking-based utilisation provide different perspectives: booking counts indicate demand frequency, while utilisation measures the proportion of eligible days occupied by confirmed or completed bookings. The distinction between these metrics is important when interpreting equipment activity. The weather advisory and maintenance indicators provide supplementary information. However, their current implementation is limited. Weather warnings are advisory, while maintenance information is based on a usage threshold rather than sensor data or predictive modelling. The archived test evidence provides support for the functional logic covered by the recorded tests. However, it does not establish performance under production workloads, reliability in poor-network rural environments or user acceptance among farmers.

I. Discussion Against Research Questions

1) *RQ1: How can multiple farmer-specific requirements be combined to rank eligible agricultural equipment?* KrishiYantra uses a weighted normalisation model to combine operation compatibility, land suitability, budget headroom, availability, owner rating and distance. Hard eligibility conditions are applied before weighted ranking. Missing criterion data are handled by renormalising the available weights.
2) *RQ2: How can recommendation and date-based booking validation be integrated?* The recommendation module filters equipment using availability information, while the booking service performs a second availability validation at submission time. This reduces the risk of accepting a request based on outdated availability information.
3) *RQ3: How can booking records be transformed into equipment utilisation and demand indicators?* The analytics module derives booking counts, trends, revenue summaries and booking-based utilisation from application records. Overlapping booked days are merged to avoid counting the same calendar day more than once.
4) *RQ4: How can cooperative booking support shared access through transparent cost allocation?* The cooperative module divides the estimated rental cost equally among the participating group members. This provides a transparent allocation calculation, although payment completion and settlement among all members are outside the claim made in this study.
5) *RQ5: What functional capabilities and limitations are observed?* The application integrates recommendation, booking, cooperative allocation and analytics in a single web application. Its limitations include the absence of field evaluation, the use of fixed recommendation weights, dependence on the quality of listing information, basic maintenance indicators, advisory-only weather information and the lack of measured production-scale performance.

V. LIMITATIONS AND FUTURE SCOPE

A. Limitations

The current study has several limitations.

1) *No Field Deployment Evaluation:* The application has not been evaluated through a controlled field deployment involving farmers and equipment owners. Therefore, farmer satisfaction, adoption, accessibility and economic impact cannot be established.
2) *Fixed Recommendation Weights:* The recommendation mechanism uses predefined weights. The weights have not been statistically calibrated using farmer preferences or historical rental outcomes.
3) *Data Quality Dependence:* Recommendation quality depends on accurate equipment specifications, coverage capacity, rental rates, ratings, location coordinates and availability records.
4) *Availability Concurrency:* The booking service revalidates availability when a request is submitted. However, the current evaluation does not establish the application's behaviour under simultaneous high-volume booking requests or guarantee database-level concurrency control under all deployment conditions.
5) *Basic Maintenance Indicators:* The maintenance functionality is threshold-based. It does not include sensor-based monitoring, predictive models, maintenance history or automated service scheduling.
6) *Advisory Weather Integration:* Weather information is provided as an advisory and is not used for automatic booking modification or recommendation ranking.
7) *Booking-Based Utilisation:* Utilisation is derived from booking records and does not measure actual machine operating hours. Maintenance downtime is not excluded from the available-day denominator.
8) *Limited Performance Evidence:* No fresh load, stress, latency or production-availability test was conducted for this study.
9) *Synthetic Illustrations:* Numerical examples in the results section demonstrate the system's calculations. They do not represent measured farmer transactions or live platform outcomes.

B. Future Scope

Future research and development can extend KrishiYantra in several directions.

1) *Adaptive Recommendation Weights:* Recommendation weights can be calibrated using farmer feedback, historical booking data and multi-criteria decision-making methods.
2) *Advanced Availability Management:* Database-level locking, transaction isolation and concurrency testing can be explored to strengthen booking consistency under simultaneous requests.
3) *Geospatial Enhancements:* More detailed location services, route distance and transport cost estimation can improve the practical relevance of distance-based recommendations
4) *Predictive Demand Analytics:* Historical booking records can be used to investigate seasonal demand forecasting and equipment allocation.
5) *Maintenance Management:* Maintenance history, service scheduling, equipment condition records and sensor-based monitoring can extend the current threshold indicators.
6) *Improved Weather Intelligence:* Weather information can be incorporated into decision support through configurable advisories, while preserving farmer control over booking decisions.
7) *Field Evaluation:* A pilot study involving farmers and equipment owners can evaluate usability, accessibility, booking completion, perceived affordability and operational benefits.
8) *Scalability and Security Testing:* Load testing, performance measurement, security assessment and deployment monitoring are necessary before production-scale use.
9) *Multilingual and Low-Bandwidth Support:* Regional-language interfaces and optimised low-bandwidth workflows may improve accessibility in rural environments.

VI. CONCLUSION

This paper presented KrishiYantra, an integrated web-based decision-support platform for agricultural equipment sharing. The application combines multi-criteria equipment recommendation, date-based booking, cooperative cost allocation and booking-derived utilisation analytics within a role-based architecture. The recommendation mechanism evaluates eligible equipment using operation compatibility, land suitability, budget headroom, availability, owner rating and geographical distance. The booking module applies inclusive date-overlap validation and rechecks availability at submission time.

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Cooperative booking supports equal allocation of estimated rental costs among group members. The analytics module derives equipment demand and booking-based utilisation indicators from stored booking records.

The application also incorporates payment integration, equipment reviews, weather advisories and basic usage-threshold maintenance indicators. Functional evidence from archived automated test reports covers 105 test cases, with no recorded failures, errors or skipped tests in those reports. Synthetic examples illustrate the behaviour of the recommendation, booking, cooperative allocation and utilisation calculations.

The principal contribution of this work is the integration of these complementary functions in a single implemented application. The study does not establish field-level improvements in productivity, income or equipment utilisation. Further research involving real users, operational data, performance testing and field deployment is required to evaluate the platform's practical effectiveness.

KrishiYantra provides a software implementation that can serve as a foundation for further research into accessible agricultural equipment-sharing systems and data-supported custom hiring services.

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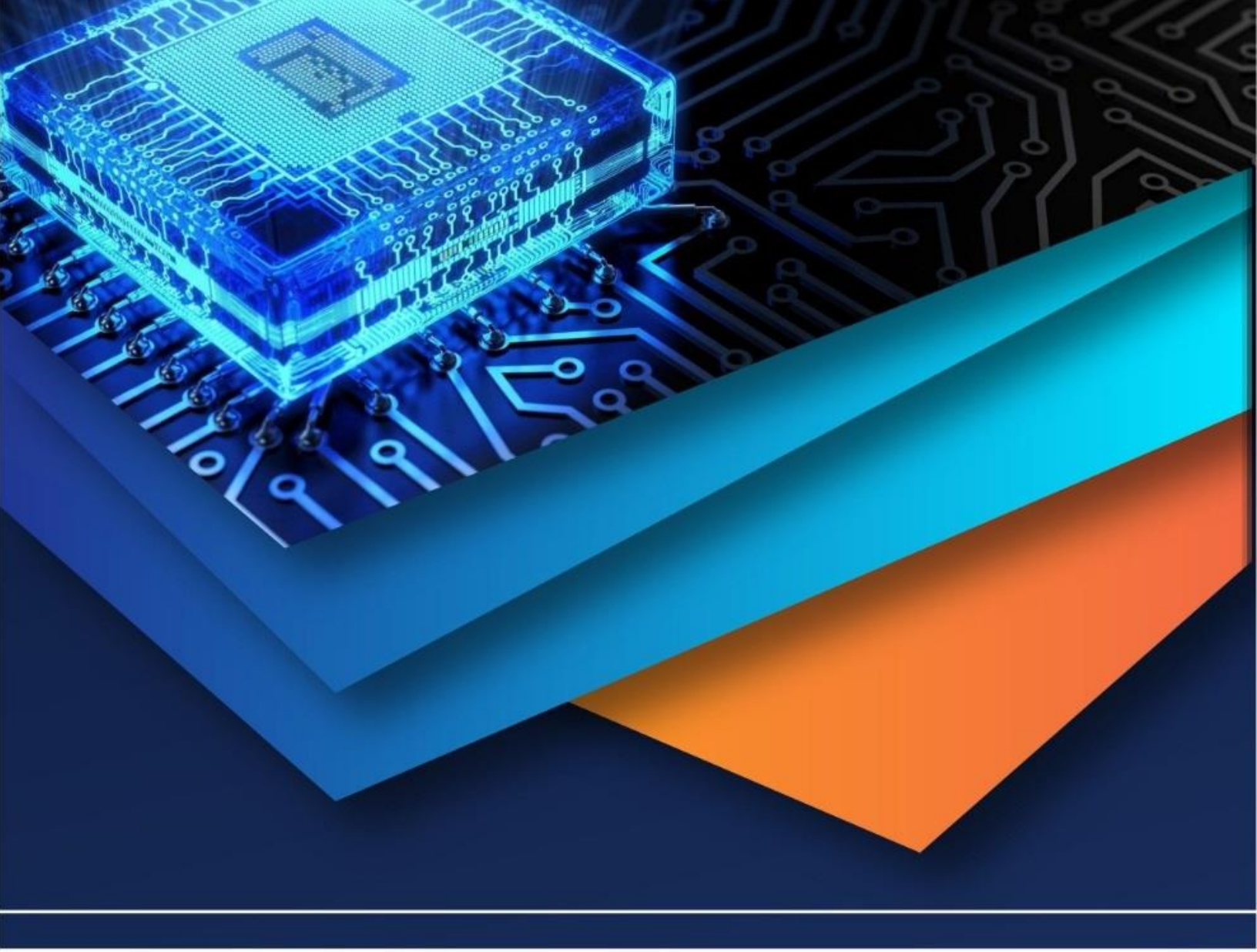

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